IRON

AS

A MATERIAL OF CONSTRUCTION:

BEING

THE SUBSTANCE OF A COURSE OF LECTURES DELIVERED AT THE ROYAL SCHOOL OF NAVAL ARCHITECTURE, SOUTH KENSINGTON.

Revised and Enlarged,

TO FORM

A HANDBOOK FOR THE USE OF STUDENTS IN ENGINEERING.

BY

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PREFACE.

A FEW years ago I had the honour of giving to the students of the Royal School of Naval Architecture, at South Kensington, a series of lectures on "The Use and Application of Iron to form Mechanical Structures."

It has been suggested that the matter prepared for these lectures might be made useful in the technical education of other students in engineering. It is highly requisite that such students should acquire a thorough knowledge of the nature and properties of a material with which they will have so largely to deal; and although the great school for acquiring this knowledge must be practical experience, yet no one can doubt that much may be usefully done to prepare the way, by placing before the student the large amount of information already collected on the subject by competent hands.

To do this in a simple, clear, and convenient manner has been my object in the present publication. I claim no originality or novelty in the scientific treatment of the subject; and the experimental data are, of course, due to the various authorities whose names are attached to them. But for the general authority of the work I am able to plead a practical experience of forty years in the use and application of iron for engineering purposes, and an extent and variety of opportunity for observation which fall to the lot of few in my profession.

I have revised the original lectures, and have made considerable additions, with a view of rendering the information more complete, and of bringing it down to the present state

of knowledge; but I have not thought it necessary to alter the colloquial and familiar style of the first composition.

In a work which professes to compile useful information from all available sources, it has been impossible for me to give special references in every case. I prefer to annex a list of works I have consulted; and not only to express in a single acknowledgment my indebtedness to them, but also to recommend them, emphatically, to all engineering students who may wish to carry further their study of the great subject here offered to their notice.

W. P.

GREAT GEORGE STREET, WESTMINSTER,
APRIL, 1872.

LIST OF WORKS BEARING ON THE PRODUCTION, NATURE, AND PROPERTIES OF IRON.

'The Manufacture of Iron in all its Various Branches.' By Frederick Overman. Philadelphia, 1856.

'A Treatise on Metallurgy.' By Frederick Overman. New York, 1864.

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'The Iron Manufacture of Great Britain.' By W. Truran. Second Edition. London, 1862.

'Metallurgy: Iron and Steel.' By John Percy, M.D., F.R.S. London, 1864.

'A Treatise on the Metallurgy of Iron.' By H. Bauermann, F.G.S. London, 1868.

'A Practical Treatise on Metallurgy' (adapted from Kerl). By William Crookes, F.R.S., and Ernst Röhrig. London, 1869.

'An Essay on the Strength and Stress of Timber.' By Peter Barlow. London, 1817.

'Practical Essay on the Strength of Cast Iron and other Metals.' By Thomas Tredgold. (Original Work, 1822.) Fourth Edition, with

Notes: and a Second Volume of 'Experimental Researches.' By Eaton Hodgkinson, F.R.S., 1842.

'Report of the Commissioners appointed to inquire into the Application of Iron to Railway Structures.' (Parliamentary Blue Book.) London, 1849.

'The Britannia and Conway Tubular Bridges.' By Edwin Clark. (Published under the supervision of Robert Stephenson.) London, 1850.

'On the Physical Principles involved in the Construction of Artillery.' By Robert Mallet, F.R.S. London, 1856.

'Reports of Experiments on the Strength and other Properties of Metals for Cannon.' Published by authority of the American Government. 1856.

'Experiments at the Royal Arsenal, Woolwich, on Cast Iron for the Manufacture of Cannon.' Parliamentary Paper, 1858, No. 497.

'Useful Information for Engineers.' By William Fairbairn, F.R.S., &c., &c. London, 1860.

'Résistance des Matériaux.' Par Arthur Morin. Third Edition. Paris, 1862.

'Results of an Experimental Inquiry into the Comparative Tensile Strength and other Properties of various kinds of Wrought Iron and Steel.' By David Kirkaldy. Glasgow, 1862.

'The Application of Cast and Wrought Iron to Building Purposes.' By William Fairbairn. Third Edition. London, 1864.

'The Elasticity, Extensibility, and Tensile Strength of Iron and Steel.' By Knut Styffe. Translated by C. P. Sandberg. London, 1869.

'Applied Mechanics.' By W. J. Macquorn Rankine, F.R.SS.L. and E., &c., &c. London, 1858.

'A Manual of Civil Engineering.' By W. J. Macquorn Rankine. London, 1862.

Various Papers in the Transactions of the Royal Society, of the British Association, and of the Institution of Civil Engineers.

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IRON

AS

A MATERIAL OF CONSTRUCTION.

INTRODUCTION.

1. The object of the following pages is to provide the Engineering student with a manual of practical information on the nature and properties of the material which now enters, perhaps more prominently than any other, into engineering designs. A century ago the structures with which engineers had to do were built almost entirely of stone, brick, or timber; in modern days these materials have become largely superseded by iron. It is questionable whether this substitution is not being carried too far, and whether the new perishable substance is not frequently adopted for the sake of cheapness, or facility of construction, in cases where the more durable but less tractable material, stone, would be more appropriate, more noble, and more worthy of the profession. But, however this may be, it is certain that the modern engineer who wishes to be master of his art must be thoroughly conversant with the nature and properties of iron as a constructive material, and thoroughly competent to adapt it to any structural purposes for which the present wants of society may demand its application.

2. Now there is no dearth of published information on certain subjects connected with iron. In the first place, on

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the *Metallurgy and Manufacture of Iron* there are the admirable and comprehensive works of Overman, Percy, Bauermann, Crookes, Truran, and many others. And secondly, on the *Design of Structures in Iron*, such as bridges, steamboats, machinery, &c., &c., there are many excellent works, and almost a superabundance of plates and drawings, illustrating the construction of such works in every variety, and in the fullest detail.

3. But a little consideration will show that there is a very wide and important gap between these two branches of information. The business of the metallurgist ends with the production of iron in a marketable shape; he does not concern himself with its further employment. It is at this point that the duty of the engineer begins. He finds the material in the market in an immense variety of forms, and possessed of a still wider variety of qualities and properties; and as he must necessarily select his material before any of his constructive science can come into play, he must, in order to make a suitable choice, be possessed to a large extent of a species of knowledge which he has not derived either from the metallurgist or the scientific constructor; namely, the knowledge of the NATURE AND PROPERTIES OF IRON AS A MATERIAL OF CONSTRUCTION.

4. This branch of knowledge is a very wide one, and it is essentially practical. Theory is of little use in its development; it is all obtained by observation and experience. Many practical engineers have devoted the best years of their lives to its acquisition, but there are many members of the profession who have had no opportunity of doing this, and to whom the want of such knowledge must always be a disadvantage, causing them to rely on others (often on contractors, whose interest is by no means in unison with

their own) for judgment which it ought to be their own personal prerogative to apply.

5. It is the object of the present work to do something towards filling this gap, by offering, for the use of students in engineering, a large amount of information, gained or confirmed by practical experience, on the important point referred to. It is not pretended that any book-learning of this kind can supply the place of practical observation, which, on so essentially practical a matter, must ever be the most valuable of all knowledge; but at the same time it is undoubtedly the case with this as with other practical branches of the profession, that when such observation is judiciously guided by previous study, the acquirement of knowledge is immensely facilitated, and its results are rendered much more trustworthy and useful.

6. I have not entered into any theoretical discussions as to the strength of materials generally, a great and important subject which will be better studied in other works. The object here being exclusively practical, I have only introduced such theoretical matter as is necessary to explain the bearing of the facts given, and to guide their practical application.

7. I may further remark that it is no essential part of the present work to treat of the *production* of iron, involving its metallurgy and chemistry, but I have thought it desirable, for the sake of completeness, to add two short chapters on this head, compiled chiefly from the valuable works mentioned in Art. 2, to which the student is referred for fuller information.

CHAPTER I.

PRODUCTION OF PIG IRON.

8. The term *iron*, though giving to the chemist a perfectly definite idea, is popularly used in a very wide sense, something like the word *timber*. This latter term comprehends a variety of *genera*, each of which is again subdivided into different *species;* and so we may say that iron is a family name, comprehending all classes and varieties of ferruginous material.

It is divided off, in the first place, into three great classes, very distinct and different from each other, *viz.:* cast iron, malleable iron, and steel, and each of which is subdivided again into a great number of different varieties.

The distinction between the three classes, when considered chemically, is very slight; consisting almost entirely in minute differences in the proportion they contain of a foreign substance, *carbon*, combined with the iron. Malleable iron is iron nearly approaching a state of purity; steel has a small portion of carbon; and cast iron a larger portion, but still only a small percentage of the whole.

But the mechanical and practical differences between the three classes are very great indeed, sog reat, in fact, as to constitute them, as regards their use, entirely different materials.

Each class further contains many sub-varieties, differing more or less in their mechanical properties; the differences being caused either by the admixture of foreign substances, or by variations in the manipulation.

9. These different kinds of iron are obtained, by different processes, from ores which are found plentifully over the earth's surface. In some cases the purest material, malleable iron, may be obtained in a very simple manner, *i. e.* by merely exposing a certain kind of ore to heat in contact with charcoal fuel, the effect of which is to reduce the ore to a metallic state. This was the earliest mode of producing iron, and it prevails in some parts of the world down to the present day.

10. But the supply of iron obtained in this mode would necessarily be very small, not only on account of the scarcity of ore sufficiently good to be amenable to such simple treatment, but from the want of sufficient wood for fuel. The earliest ironworks established in England, namely in the southern counties, were worked on this plan, but from the large inroads the ironmasters made on the timber of the district, it was found necessary to prohibit the manufacture by the strong arm of the law.

The introduction of the use of pit coal for iron smelting, about the middle of the last century, at once changed the aspect of the iron manufacture, as it not only brought into use the great fuel-stores of the carboniferous formations, but made available all the immense masses of inferior ore existing in the country.

11. This change brought about a variation in the mode of production of the iron. With coal it was no longer possible conveniently to produce the purer variety, malleable iron; it was easier to get in the first instance the most impure form, *cast iron*, from which the other varieties were afterwards made by subsequent treatment.

The ordinary modern process of iron production may therefore be briefly stated as follows:—The ore is smelted

with coal or coke in a blast furnace, and the product is *pig iron*, a form of cast iron, being metallic iron combined with the highest proportion of carbon, and containing also other impurities.

To produce malleable iron this pig iron is subjected to a process called *puddling*, by which carbon and other impurities are taken out, and the iron assumes a purer condition.

To produce steel, wrought iron is submitted to a process called cementation, the object of which is to re-introduce a certain dose of carbon, sufficient to give the metal the peculiar steely character.

It will be desirable now to follow out these processes somewhat more in detail, so far at least as the production of cast and malleable iron is concerned.

IRON ORES.

12. The combinations of iron found native are very varied in their character; but the only forms used for the production of the metal in commerce are certain oxides and carbonates, of which the chief mineralogical characteristics are as follow :—

The *sesquioxide* (Percy), or the *peroxide* (Bauermann) of iron ($Fe^2 O^3$), occurs abundantly in a nearly pure state, forming the hard and brilliant mineral known as *hematite*. It contains 70 per cent. of iron, and is the basis of a large number of iron ores, known under the following names: *—

Specular iron ore, *oligiste*, or *iron glance*, includes the brilliant, hard, well-crystallized forms, such as those of Elba, Brazil, Vesuvius, &c.

Micaceous iron ore includes all the scaly crystalline varieties, such as those of South Devon, which are loosely coherent, and similar to graphite in structure.

* Bauermann, p. 50.

Kidney ore includes the hard botryoidal forms, such as those of Cumberland, which are devoid of metallic lustre.

The term *Red Hematite* is commonly used by English iron smelters for all minerals consisting essentially of anhydrous peroxide of iron.

The sesquioxide of iron is largely manufactured in the state of amorphous powder, used as a pigment (chiefly in the ceramic arts), to produce tints of red, brown, and violet. It is also used for polishing plate-glass, and when very finely levigated, forms the plate-powder called *rouge*.

Brown iron ore is a term used to designate the compact and earthy minerals, in which water is combined with the peroxide of iron ($2\ Fe^2\ O^3 + 3\ H\ O$), the percentage of iron according to the formula being 59·9.

A combination of the peroxide with the protoxide ($Fe\ O$), in equal equivalents, occurs in nature as a definite mineral known as *magnetite*, or magnetic iron ore. This contains 72·41 per cent. of iron.

The oxides of iron combine freely with carbonic acid, forming carbonate of iron. The most important of these is an anhydrous carbonate ($Fe\ O\ .\ C\ O^2$), which is found abundantly in nature, either crystallized pure, or in combination with carbonate of lime, clay, or other substances. The former crystalline varieties are called *spathic ores*, while the term *clay band* or *clay ironstone* is applied to the amorphous argillaceous ore found in the coal measures, and *black band* to that containing bituminous or carbonaceous matter.

13. The above descriptions are on a mineralogical basis; but in the actual state of things the minerals are found largely mixed up with foreign earthy matters, the amount and nature of which have an important influence on the quality of the iron produced and on the economy of production.

It would be impossible here to give any full account of the ores actually used for iron making; a brief notice of some of the more important ones must suffice.

Iron ores are found in geological formations of all ages, but the greatest development appears to be in the older rocks. The largest and richest deposits are contained in pre-Silurian strata, such as the Laurentian and Huronian systems of North America, and the old gneiss and schists of Scandinavia. Spathic ores and high-class hematites are characteristically abundant in the Devonian rocks of Germany and the south of England. The carboniferous period is especially marked by the presence of interstratified carbonates (Staffordshire, Yorkshire, Scotland, and South Wales, for example), while the most important deposits of red hematite in this country are contained in the carboniferous limestones of Cumberland and Lancashire. In the secondary rocks, the chief iron-bearing members are the Wealden and lower greensand (Sussex), and the middle lias and great oolite (Northamptonshire, Cleveland).

14. Mr. Truran classifies the ores of Great Britain into four great divisions, thus :—

A.—The argillaceous ores of the coal formations, having clay, but sometimes silica, as the chief impurity.

All the great coal formations hitherto discovered contain iron ores in greater or less abundance. Staffordshire, Wales, Derbyshire, Shropshire, and the Scotch coal-fields contain valuable seams; and South Wales stands pre-eminent for the number and richness of its argillaceous iron ores. The aggregate thickness of the seams measures 21 feet; the richest yield upwards of 40 per cent. of metallic iron, and the average exceeds 32 per cent.

B.—The carbonaceous ores of the coal formations, distinguished by their large percentage of carbon.

The most valuable seams of this belong to the Scotch coal-fields, and are often known by the name of *black band.* The richest give above 40 per cent. of metallic iron. Some of this ore is also found in South Wales.

These two kinds, A and B, together form probably one-half of the total annual produce of the United Kingdom. They are often worked in conjunction with coal seams in the same pits. The yield of ironstone in some of these districts is from 2000 to 7000 tons per acre of land.

C.—The calcareous or spathic ores, or the sparry carbonates of iron, having lime as their chief earthy admixture.

These are principally obtained from workings in the carboniferous or mountain limestone, and are found chiefly in the Forest of Dean, Lancashire, and Cumberland, but also to a small extent in Staffordshire, Yorkshire, Scotland, Derbyshire, Somersetshire, and South Wales.

The average yield of the Forest of Dean ores is about 37½ per cent.

D.—The siliceous ores, having silica as their predominating earth. This class is subdivided into the red and brown hematites, the ores of the oolitic formation, the white carbonates, and the magnetic oxides.

The red hematites of Lancashire and Cumberland are probably the richest ores of iron in this country; they occur in magnificent beds, 15, 30, and even 60 feet in thickness. They are of extreme purity, containing 90 to 95 per cent. of peroxide of iron, or 65 of metallic iron. The pig made from them is peculiarly in demand for making steel by the Bessemer process, as well as for mixing with inferior kinds of metal.

The beds of ironstone lately opened in the oolitic Cleveland district of Yorkshire, are of great extent, yielding on an average about 20,000 tons per acre. The ore contains from 25 to 50 per cent. of iron.

15. It is not, however, all pure ore, or "mine," which is used for the production of iron. Since the introduction of the hot blast, pig iron has been also made from the refuse "tap cinder," coming from the puddling process, and which is found to contain a large quantity of iron. As, however, the cinder is a receptacle for impurities, the metal resulting from it is of inferior quality, and is called "cinder pig," to distinguish it from "mine pig," which is smelted from ores alone.

At the same time, cinder iron has some advantages; it is very fluid when melted, and is consequently very useful for foundry purposes where great fluidity is desired, and where strength is not important. Also, for heavy castings, and for other purposes where soundness is particularly aimed at, cinder iron is found useful as a mixture.

Calcination.

16. Before smelting the ores, it is advantageous in most cases to subject them to the action of heat, by a process called *calcination* or *roasting*, and which is effected either in the open air, by stacking the ore loosely with coal in alternate layers and setting fire to the heap, or in kilns arranged for the purpose, which are considered preferable. This process was formerly applied to nearly all ores, but since the hot blast has been introduced, it has been sometimes omitted, and the ore smelted in its raw state.

17. The advantages of the calcining operation are of two kinds, mechanical and chemical. In the first place, the amount of iron is concentrated into a smaller weight by the removal of water, carbonic acid, and other volatile matters; and as the fragments of mineral retain their form, they are rendered porous and more readily susceptible of the opera-

tions in the furnace. The second or chemical object of roasting is the expulsion of the sulphur from iron pyrites, &c., and the conversion of proto- into per- oxides, which facilitates certain subsequent operations.

The argillaceous ores lose, during the process, 20 to 30 per cent., the carbonaceous 30 to 40 per cent. of their weight. In Scotland, the coaly matter in the black-band ore is almost sufficient in itself to effect the calcination, and the loss is 40 to 50 per cent.

Smelting.

18. The reduction or smelting of iron ores is effected chemically by one sole agent, namely, *carbon*, which, applied at a high temperature, seizes the oxygen of the oxide of iron, and allows the metal to flow away in a molten state. The carbon necessary for this purpose is conveniently furnished by the *fuel* used for producing the heat; and as this is an important element in iron manufacture, it is necessary to say a few words upon it.

19. At first the kind of fuel used in the manufacture of iron was universally charcoal; and on account of its purity, compared with other kinds of fuel, it is still of great value for the best descriptions of iron, when it can be obtained in large quantities at a reasonable cost. It was used in the early ironworks in England, and it is still employed to a considerable extent for the finest Russian and Swedish irons, the wood being furnished by the large forests there.

The use of pit coal as fuel was introduced about the middle of the last century, and it was this which at once put Great Britain at the head of the iron-making countries of the world, from her large and easily accessible coal-fields, and their close association with the iron ores.

Before the introduction of the hot blast, the coal was generally converted into *coke*, to assimilate it as much as possible to the original and better material. But the hot blast has enabled ironmasters to dispense, in many cases, with the coking process, and to use raw coal in the furnaces. The quality of the iron has, however, suffered by the change, as the sulphur and other deleterious ingredients, which are partly eliminated by the process of coking, remain fully present in the furnace when raw coal is used.

It is only certain sorts of coal that are found suitable for use raw; others have been tried, but failing to give satisfactory results, the coking process has been retained.

20. In the treatment of the ores in the smelting furnace, it is necessary they should be accompanied with a proper *flux*, the object of which is to combine with the earthy matters of the ore, and form a fusible "slag" which shall separate from the iron and run easily away. The principal flux used is *limestone*, which is generally found in the neighbourhood of the coal and the ironstone. The proportion of flux used is such as is found by experience to produce the most fusible combination.

21. The operation of smelting is conducted in a *blast furnace*. All those who have visited iron-making districts must be familiar with the external appearance of this great apparatus, and a general idea of its internal construction will be obtained from the figure in Art. 25. It may be considered as a large vertical shaft or chamber, whose interior is of a bellied form, narrow at the top and bottom, and widening out in the middle. The widest part is called the *boshes* (probably a corruption of the German word *bauch*, belly), the part above is called the *stack;* and the lower part of

the furnace, where the molten materials fall and collect, is called the *hearth*.

The external structure is a massive building of masonry strengthened with iron, or indeed often enclosed in an iron casing. It is provided with large arched recesses at the lower part, to give access to the openings in the furnace hereafter mentioned.

The interior of the furnace is lined with fire-brick, to withstand the great heat. A small annular space, filled with sand or loose material, is left between the internal lining and the external structure, to allow of changes of form by expansion.

At the top of the furnace is a cylindrical chimney called the *tunnel-head*, for protecting the workmen from the heated gases, and having one or more iron doors, through which the charges of ore, fuel, and flux, are thrown into the furnace. This is surrounded by a platform for the convenience of charging, and the materials are usually raised to this level by lifts or inclined planes.

In front of the furnace, protected by a roof, is the *casting house*, where the metal is run from the furnace into moulds.

The blast air is introduced at openings a little above the hearth by small pipes called *twyers* (French *tuyaux*).

22. The dimensions of blast furnaces are very various; they are now made much larger than formerly. The conditions limiting the height are mainly due to the character of the ores and fuel (as regards their power of resisting crushing when exposed to the pressure of a tall column of material) and the power of the blast. In Cleveland, where very hard coke is employed, they are 70 feet and upwards in height, but the usual height varies in Great Britain from 45 to 60 feet; the internal diameter at the boshes, from 14 to 20 feet; and the cubic content from 4000 to 10,000 cubic feet.

23. The blast air, which has to be provided in large quantities, and at a considerable pressure, is furnished by *blast engines.* Each of these consists of a large cylinder or air pump, in which, by the direct action of a steam-engine, the air is compressed to the requisite density, being then forced out to supply the furnace. These cylinders are sometimes very large. Those at Dowlais are 12 feet in diameter and 12-feet stroke; the area of the admission valves is 56 feet; and they work twenty double strokes per minute. The main blast pipe is 5 feet in diameter. For a large blast furnace there will be required about 5000 to 6000 cubic feet of air per minute, which is compressed to such a volume as will give a pressure of three or four pounds per square inch.

The motion of the blast engine being intermittent, its delivery of air is irregular; but as the supply to the furnace must be equable, it is regulated by admitting the air into a large reservoir, usually made of wrought iron, and whose volume is several times that of the blowing cylinder; the expansion and contraction of the air in this, under the intermitting action of the supply, tend to reduce the irregularity, and to discharge it in a more equable stream.

24. Down to 1828, the air was supplied to the furnace at its natural temperature; but in that year the *hot blast*, one of the most important discoveries ever made in the iron manufacture, was introduced and patented by a Scotch engineer, Mr. J. B. Neilson. The progress of the invention, as of most other improvements, was slow. There had previously been an impression that it was advantageous to admit the air as cold as possible, and contrivances for its refrigeration had actually been used. Hence there was a great prejudice against the innovation, and moreover many practical difficulties were found in carrying it out; but the prejudices and difficulties were alike overcome by time. The heating of the air was

found to be attended with a great economy of fuel, and at the same time the working power of the furnace was increased. Hence the hot blast made its way, and it is now employed in iron smelting all over the world, the old plan being only retained for certain special makes which command an extra price, and are better produced in that way.

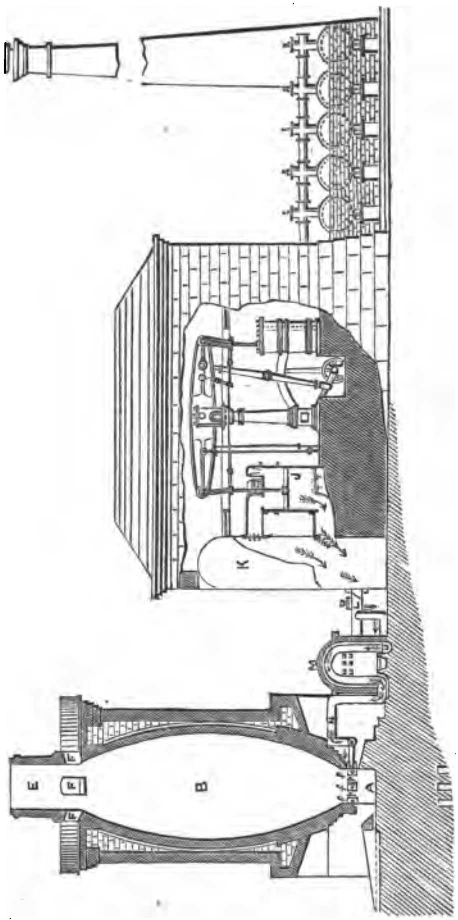
The air is heated by what is called an *oven* or *stove*, consisting of a series of tubes, placed in a chamber of fire-brick, and heated externally by a fire, or by the waste gases from the furnace. The air as it issues from the blast reservoir is made to pass through these tubes, and having thus acquired the desired temperature, is led away immediately to the twyers. The hotter the blast, the greater is the saving of fuel, but practical considerations usually limit it to about 800 degrees.

An improved form of stove has lately been introduced by Messrs. Siemens and Cowper, in which the tubes are replaced by narrow passages through brickwork; and by a particular disposition of the heating arrangements, a higher heat can be obtained than formerly, with economy in fuel.

With regard to the merits or demerits of the hot-blast process, much has been said on both sides, and the question does not even yet seem to be definitely settled. It is often asserted that the hot-blast tends to deteriorate the quality of the iron, and it is undeniable that hot-blast iron is generally of inferior quality to cold blast; but this is probably due, not to the effect of the process itself, but to the facility it has given for working inferior ores, cinder heaps, and other materials of a worse character, and so for turning upon the market a class of iron which, under the old system, could not have been made. There is no doubt that the hot-blast process has much increased and cheapened iron production, and therefore has been a benefit to the iron manufacture.

25. The following figure (borrowed from Sir William Fairbairn's work) will show in a simplified form the general arrangement of the apparatus for iron-smelting works.

FIG. 1.



The blowing engine is supplied with steam by five boilers. J is the blowing cylinder (shown in section), from which the

air is forced into the regulating receiver K, made of wrought-iron boiler-plate. From this it passes by the pipe L into the heating ovens, one of which is shown in section at M, and the pipe N conducts it, when heated, into the blast furnace B. In this, A is the hearth, B the boshes, E the tunnel-head, F F are the charging doors, *f f* the twyers.

26. Supposing now the three materials, roasted ore, flux, and fuel, to be properly prepared, in pieces of suitable size, they are weighed out in proper proportions, and introduced, in alternate charges, into the top of the blast furnace. The furnace is filled with the combined materials, and the whole mass is kept in an incandescent state by the operation of the blast, which must of course be introduced at such pressure as will cause the air to pass freely through the contents.

The action of the furnace is as follows:—The contents, being intimately mixed, and brought to an intense heat by the combustion of the fuel, are softened and rendered capable of chemical action on each other. The ore consists of oxide of iron and earthy matters, and these two elements undergo separate actions. The earthy matters are brought into the sphere of action of the limestone flux, which parts with its carbonic acid and forms with the earthy ingredients of the ore a liquid slag; while the particles of oxide of iron are attacked by the incandescent carbon of the fuel, or by the heated carbonaceous gases, or both, which rob them of their oxygen and leave the particles of metal free.

Were this all, however, the metal would not be liquid enough to flow away easily, but another effect takes place simultaneously with the freeing of the iron, namely, its combination with another portion of the carbon of the fuel, which converts it into *cast iron*, and gives it the necessary fluidity.

The result of all this is that the liquid slag and the molten metal drop down together to the hearth, or bottom of the

furnace, where they collect, in two layers, the iron, by its greater specific gravity, at the bottom, and the slag floating above it. The slag in this position serves to protect the iron from the oxidizing influence of the blast above.

27. The gases which escape from the top of the furnace contain a large portion of carbonic oxide, which is capable, by further combination with oxygen, of burning and giving out considerable heat. This was formerly allowed to vent itself into the air, forming a great flame; but of late years attention has been called to this waste of heat, and the gases have been led away by proper channels to places where, by combustion, they form useful fuel.

28. The molten iron is allowed to accumulate for twelve hours, more or less, when it is drawn off by a narrow vertical slit at the bottom of the hearth, called the *tap-hole*. During the time that the hearth is filling, this hole is stopped by a packing of sand, rammed in tight, which is easily removed by a pointed bar, when the time comes for running the metal off.

The iron then runs into a series of grooves, or furrows, formed in a sand floor immediately in front of the tap-hole, and these, when separated from each other, form *pigs*. They are of a convenient size for sale and handling, usually about 4 or 5 feet long, and of a D section, 3 or 4 inches wide and deep, and weighing about 1½ to 2 cwt. each.

When the casting is completed the tap-hole is again closed, and the collection of the iron proceeds as before. In this way a blast furnace is kept continually going, night and day, and never ceases to work till repairs are necessary.

29. The slag or molten cinder flows out of itself from a notch or hole in the hearth, situated at a little higher level

than the tap-hole; so that when the accumulation of iron and slag is so great as to bring the slag to this level it is discharged. It is generally received into small boxes, or trucks, by which it is carried away, and when hard it is deposited in a waste heap at some distance.

The slag indicates by its appearance the manner in which the furnace is working. Thus: if it be liquid, nearly transparent, or of a light greyish colour, and with a fracture like limestone, a favourable state of the furnace is inferred. Tints of blue, yellow, or green are caused by a portion of the oxide of iron passing into it, and show the furnace is working cold. The worst appearance of the cinder, however, is a deep brown, or black colour, the slag flowing in a broad, hot, rugged stream; this indicates that the supply of fuel is not sufficient to deoxidize the whole of the ore.

30. The pig iron produced from blast furnaces is of several different kinds, and is used for different purposes, according to the quality. There are two main distinctions; namely, *foundry pig*, which is used for re-melting for foundry purposes, to make articles in cast iron; and *forge pig*, which is used to make malleable iron by the puddling process.

The former class—*viz.* foundry pig—is distinguished by containing the most graphitic carbon in its composition; it is soft, and of an open, large, crystalline texture, and of a dull grey colour. There are several varieties of this kind of pig, distinguished generally by numbers, from 1 to 3: the No. 1 being the largest grained, and the greyest in colour; Nos. 2 and 3 being closer, harder, and whiter.

Beyond this the pig becomes forge pig, which contains less graphitic carbon, is hard and fine grained, and generally white, but sometimes of a mottled appearance, by the mixture of white and grey. The varieties of forge pig are difficult to reduce to any simple classification, as they depend much on

the character of the ore and the process of smelting; they are distinguished by special names, such as Mine Pigs, Best Mine Pigs, Hydrates, Cold-Blast Pigs, &c., with often the name of the maker appended.

The relative greyness or whiteness of the pig iron, although sufficient to indicate generally the purpose to which the iron is best adapted, furnishes no real standard of quality. The grey or white condition may be produced at pleasure from the same ore, by altering the conditions of the working of the furnace. With a low temperature and a high burden of materials, white iron is produced; with the contrary conditions the iron becomes grey.

Other things being equal, white iron can be produced more cheaply than grey, as the same amount of fuel is made to carry a larger burden of ore, and the charges are drawn more rapidly. As, however, the white iron can only be used for forge purposes, while the grey iron has a more extensive application and commands a higher price, the production of the more expensive product is often the most advantageous to the maker.

White pig iron melts at a lower temperature than grey, but becomes less perfectly fluid, and flows in a sluggish stream. When both kinds of metal are contained in the hearth of a blast furnace at the same time, the whitest, being the heaviest, goes to the bottom, and will be found in the first pigs obtained from the cast.

Foreign Ingredients in Iron.

31. Pig iron, although it possesses in a large degree the properties of metallic iron, is far from being pure; for in the process of smelting the freed metal has combined with a portion of the reducing agent, as well as with other substances contained in the ore, the fuel, or the flux. It will be well

here, therefore, to mention the various foreign substances which are usually found in combination with iron, and to notice the effects of their presence on the pig, or on the iron produced therefrom.

32. *Pure iron* in a compact state has been very imperfectly investigated. Certain varieties of wrought iron approach most nearly to the pure metal; but they are all in a sensible degree impure. Small specimens, as nearly pure as chemical care can get them, have been occasionally produced in the laboratory, and they are described as giving a metal approximating in whiteness to silver, extremely tenacious, malleable, softer than ordinary bar iron, and with a crystalline fracture. It has a specific gravity varying from 7·9 to 8·14.

Iron crystallizes in the cubical system. Its specific heat is about 0·114; that is, to heat 1 lb. of iron requires the same quantity of heat as is necessary to heat 0·114 lb. of water through the same number of degrees.

Its linear dilation by heat is about 0·000111 to 0·000126 for each unit of length heated 1° Centigrade.

Pure iron is fusible; but it requires a very high temperature, estimated at 1550 C. It may be fused perfectly in the metallurgist's assay furnaces, where platinum remains infusible.

It has the remarkable and very important property of continuing soft through a considerable range of temperature below its melting point. At a bright red heat it is so soft as to admit readily of changes of shape by mill, forge, and smithy operations: such as rolling, hammering, pressing, stamping, &c., &c.; and when the heat is raised to whiteness it becomes *pasty*, so that when two pieces at this temperature are pressed together, they unite intimately and firmly, which is the operation called *welding*. These operations will be treated of more particularly hereafter.

The proportions of the foreign ingredients found in marketable iron are but small, but they exercise a most powerful effect, giving rise to the remarkable varieties in the quality and properties of the material, which we shall hereafter have to consider.

33. The most important foreign element is *carbon*. Dr. Percy says:—

The influence of this element in causing variation in the physical properties of iron, is one of the most extraordinary phenomena in the whole range of metallurgy. Under the common name of iron are included virtually distinct metals which in external characters differ far more from each other than many chemically distinct metals. Without carbon the manifold uses of iron would be greatly restricted, and so far as is yet known, no other metal or mixtures of metals could be applied to these uses.

When carbon is absent, or only present in very small quantity, we have *wrought iron*, which is comparatively soft, malleable, ductile, weldable, easily forgeable, and very tenacious, but not fusible except at temperatures rarely attainable in furnaces, and not susceptible of tempering like steel.

When carbon is present in certain proportions, the limits of which cannot be exactly prescribed, we have the various kinds of *steel*, which are highly elastic, malleable, ductile, forgeable, weldable, and capable of receiving very different degrees of hardness by tempering, even so as to cut wrought iron with facility, and fusible in furnaces.

Lastly, when carbon is present in greater proportion than in steel, we have *cast iron*, which is hard, comparatively brittle, and readily fusible, but not forgeable or weldable.

The differences between these three well-known sorts of iron essentially depend on differences in the proportion of carbon, though other elements may, and often do, concur in modifying to a striking degree the qualities of this wonderful metal. Ours is emphatically the iron age, and it may be confidently asserted that no other element has contributed so largely to the civilization and happiness, and may we not also add, paradoxical as it may seem, to the misery of mankind. But let us not forget that carbon has done its share in this good and evil work.

The following indications as to the quantities of carbon in

the different varieties of the ferruginous material, are given by Dr. Percy, on the authority of the celebrated German metallurgist, Karsten.

It is considered that the maximum of carbon with which iron can combine is 5·93 per cent.

Pure iron, perfectly free from carbon, is so soft, that it offers but little resistance to friction, and is therefore unfitted for most of the purposes to which the ordinary metal is applied. When combined with carbon not exceeding certain limits, it increases in tenacity, elasticity, malleability, ductility, and hardness, and becomes "steely."

The passage from this into steel is so gradual and insensible, that it is impossible to pronounce where steely iron ends and steel begins. But when the property of hardening by sudden cooling after heating is well developed, so that sparks will be given with flint, the metal becomes decidedly "steel." The proportion of carbon necessary to give this quality is influenced by other ingredients which the metal may contain; the more free it is from foreign matters—especially silicon, sulphur, and phosphorus—the larger is the amount of carbon necessary. In very pure iron 0·35 to 0·5 per cent. is necessary; in less pure, 0·2 to 0·25 will suffice. From this to 1·0 or 1·5 per cent. gives the ordinary range for steel of various kinds.

Above 1·5 per cent. of carbon will give still greater hardness, but only at the expense of tenacity and weldability; with 1·75 per cent. the last property is almost completely lost. With 1·8 per cent. iron may still, with great difficulty, be worked and drawn out under the hammer; and although very bad, it yet retains considerable tenacity.

When the carbon rises to 1·9 per cent., or more, the metal ceases to be malleable while hot, and 2 per cent. appears to be the limit between steel and cast iron; when the metal in the softened state can no longer be drawn out without cracking and breaking to pieces under the hammer.

From 2 per cent. therefore to the maximum, *cast iron* is produced, and the larger the proportion of carbon, the harder, whiter, and more fusible does it become. An example of a highly carbonized and crystalline white iron is what is called "Spiegeleisen" pig, containing about 5 per cent. of carbon. It crystallizes, as its name implies, with large mirror-like cleavage planes.

The following Table, given by M. Bauermann, will conveniently illustrate the above data :—

	Name.	Percentage of Carbon.	Properties.
1	Malleable Iron	0·25	Is not sensibly hardened by sudden cooling.
2	Steely Iron ..	0·35	Can be slightly hardened by quenching.
3	Steel	0·50	Gives sparks with a flint when hardened.
4	"	1·00 to 1·50	Limits for steel of maximum hardness and tenacity.
5	"	1·75	Superior limit of welding steel.
6	"	1·80	Very hard cast steel, forging with great difficulty.
7	"	1·90	Not malleable hot.
8	Cast Iron ..	2·00	Lower limits of cast iron cannot be hammered.
9	" ..	6·00	Highest carburetted compound obtainable.

But independently of the large variations of the *quantity* of carbon in iron, and the remarkable series of changes due thereto, there is another element of variation in respect to this admixture, which also produces very diversified results : the carbon may be present in the metal in different *forms*. It may either be perfectly and chemically *combined* with the iron, or it may be separate, and only mechanically diffused. These differences are best illustrated by well-known facts in regard to pig or cast iron. Of this there are two distinct

kinds, grey and white. They differ widely in colour, hardness, brittleness, tenacity, and fusibility. Grey iron has a higher melting point than white iron, and in fusing it passes almost instantly from the solid to the liquid state, when it becomes very fluid. White iron, on the other hand, is acted on at lower temperature, when it becomes first soft and then pasty before melting. It was formerly supposed that these differences were due to the larger amount of carbon in grey than in white iron; but this opinion was found to be erroneous, as grey iron was often convertible into white, and *vice versâ*, without any change in the proportion of carbon. The explanation now given is that in white iron the carbon is in chemical combination, whereas in grey iron it is partly separate and diffused through the mass in the form of crystals of "graphite," which give the grey fracture and the soft texture. Changes in the condition of the carbon are very common in manufacturing processes,* and will be noticed hereafter. They are very interesting in steel, as they are supposed to have to do, in some way not yet clearly known, with the remarkable changes produced in it by tempering. It is supposed that the state of combination in steel depends on the treatment to which the metal is subjected. In soft steel it is supposed to be graphitic, but in hard, chemically combined; and the tempering process probably depends on changes produced in this particular.

Mr. Styffe says (Art. 33):—

When the proportion of carbon in iron or steel is increased, whilst other conditions remain the same, the limit of elasticity, as well as the tensile strength, is to a certain extent increased; but the extensibility, on the contrary, is diminished. The tensile strength, which in good soft iron may be estimated in round numbers at 21½ tons per square inch, seems to attain its maximum in steel containing about 1·2 per cent. of carbon, and is then, in good cast steel or Bessemer steel, about 61½ tons per square inch.

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* See remarks at length by Dr. Percy, page 116, &c.

34. *Silicon* exists largely in iron ores. It is mostly separated in the glassy slag and cinder which form the refuse of the smelting process; but it enters also to a considerable extent into the resulting pig iron. When this is converted into malleable iron, silica is further separated in the refining and puddling furnaces, and also squeezed out in the hammering and rolling operations. Indeed it is to the more and more perfect expulsion of this substance that the improvement of wrought iron, by re-beating and re-working, is in a great measure due. When present in wrought iron it renders it hard and brittle.

35. Iron has a strong affinity for *sulphur*, and many varieties of the compound exist in nature, of which the best known is that called *iron pyrites*, a bisulphide of iron, so abundantly found in coal. Sulphur is a very common impurity in manufactured iron, being derived either from the ore or the fuel, or both. A small proportion of it in iron imparts the defect of red shortness.

36. *Phosphorus* will combine with red-hot iron, causing much increase of incandescence. When it is present in the ore it passes easily into the metal, and has then, if in more than a very small quantity, a decided effect on the malleability and strength, rendering it what is called *cold short*, *i.e.* brittle when cold. Malleable iron containing 0·3 per cent. of phosphorus is somewhat hardened, but is not sensibly affected in tenacity; with 0·5 per cent. it becomes somewhat "cold short;" with 0·8 this quality is very decided; and 1·0 per cent. makes the metal very brittle. The effect of phosphorus on cast iron is to diminish its strength, but to increase its fusibility: thus making it less suitable for engineering purposes, but more so for delicate ornamental work.

Mr. Styffe says (Art. 33) that a small proportion of phos-

phorus in iron generally raises the limit of elasticity and the tensile strength, and therefore also the hardness of the metal, but at the same time it diminishes its extensibility. This, however, is dependent on certain conditions, which limit the general application of the rule.

37. *Manganese* is of great value in iron which is intended to be converted into steel by puddling, as it tends to hinder the removal of carbon, oxide of manganese being undecomposable by carbon in an oxidizing atmosphere.

38. *Arsenic* is a rare impurity: when it occurs it produces *red shortness* in wrought iron, and is favourable in cast iron for the operation called "chilling."

39. The presence of *nitrogen* has been supposed to have some effect, particularly in steel; but the evidence on this point is still obscure. Nitrogen is introduced by the process of casehardening, as hereafter explained.

40. *Tungsten* has the property of rendering cast steel very hard and tenacious. *Vanadium* is supposed to render iron peculiarly fitted for wire drawing.

41. The analyses of a great variety of samples of pig iron (Bauermann, page 234, 5) show the general amount of foreign ingredients as follows:—

	Per cent.
Carbon, partly combined, and partly in a graphitic form	2·3 to 5·5
Silicon	0·13 „ 5·7
Manganese	0·0 „ 7·6
Sulphur	0·0 „ 0·87
Phosphorus	0·0 „ 1·66

Statistics.

42. The make of pig iron from a blast furnace varies from 15 to 40 tons per day. The average consumption of coal in

Staffordshire per ton of metal produced is, for hot blast from 55 to 60 cwt.; for cold blast from 60 to 70 cwt., besides 2 cwt. for calcining, and 15 to 22 cwt. for the stoves and steam-boilers where the gas-saving apparatus is not used.

43. The following are the details of charges employed at Dowlais, South Wales, for different kinds of pig iron; the quantities are in cwts. for every ton of iron made.

	Foundry Pig.	White Forge-Pig.	Common Forge-Pig.
	cwt.	cwt.	cwt.
Calcined "mine" (fresh ore) ..	48	28	..
Red hematite ore	..	10	16
Forge and refinery cinder ..	..	10	25
Limestone	17	14	16
Coal	50	42	36
Weekly make	130 tons.	170 tons.	190 tons.

In the Cleveland district, the average charge per ton of iron is stated at—

	Cwt.
Cleveland ore	70
Limestone	15
Coke	26
Coal for calcining, stoves, and boilers	10

44. The annual consumption of iron ore in the United Kingdom is in round numbers about 10,000,000 tons. The relative proportions of the different minerals are as follows:—

	Per cent.
Argillaceous and black-band ores of the coal measures ..	42
Cleveland ores	28
Red hematite	15
Brown hematite and limonite	13
Spathic and foreign ores	2
	100

45. The estimated production of pig iron in the principal iron-making countries of the world was estimated as follows, for the year 1865.

	Furnaces.	Tons.
United Kingdom	613	4,768,000
France	430	1,195,000
United States	260	1,120,000
Belgium	52	450,000
Russia	..	300,000
Austria	..	314,000
Sweden and Norway ..	253	246,000
Italy	..	37,500
Spain	..	60,000

CHAPTER II.

PRODUCTION OF MALLEABLE IRON.

46. I now proceed to describe the mode of production of the purer form of the material, *malleable* or *wrought iron.*

This variety may, as already stated, be produced directly from the ore, and before the introduction of the blast furnace this was the usual way in which iron was procured. The chief modern representative of the "bloomeries," or hearths used for the purpose, is the so-called Catalan or Corsican forge, which still survives in the Pyrenees and a few other isolated localities, in the south of Europe. The ore, usually a rich and easily reducible brown hematite, is mixed with charcoal and placed in a hollow hearth, into which a blast of air is introduced by a twyer. The charcoal being ignited, the blast is turned on, and a strong heat is kept up till the reduced iron appears in the form of spongy or pasty masses, which are then withdrawn, worked together into a lump or ball, and forged under the hammer into a rough bar or bloom. The iron so obtained is generally of good quality, though often hard and steely.

In India, wrought iron is also made directly from the ore, either in shallow hearths with an artificial blast, or in furnaces with shafts. In either case the dimensions are small, and the blooms produced vary from 20 lbs. to 2 cwt. in weight.

47. But the ordinary mode of producing malleable iron is to manufacture it from cast or pig iron by a process called

puddling,* *i. e.* exposing the pig iron in a melted state to the action of oxygen, which carries off the carbon, and leaves the iron in the malleable state which is characteristic of the pure metal.

48. The pig used in preference for conversion into malleable iron is the white variety, usually termed *forge pig*, containing least carbon. Grey pig is, however, not excluded, as it can be rendered tractable by a process which is very generally used as a preliminary to puddling, that is, the process called *refining*.

Refining.

49. This process is commonly used in the Welsh ironworks, and to a certain extent in the other iron-making districts of this country. In the manufacture of the finest qualities of wrought iron it is invariably adopted, but with the inferior kinds it is not so much employed as formerly.

It is a combination of chemical and mechanical processes, whereby the material is deprived of a portion of the extraneous matters contracted in the blast furnace. The crude

* I have not alluded here to the production of wrought iron by the Bessemer process, as the notice of this process belongs more properly to the head of steel. The metal produced by the Bessemer method is generally called steel, but in many cases, where an endeavour is made to produce a peculiarly soft and ductile material, there is no doubt that it differs little or nothing from iron, that it is, in fact, only malleable iron under another name. I had once occasion to examine some professedly "cast steel" axles, made for exportation, but observing that their behaviour in the lathe was very unlike that of steel, I tested some fragments of them, and found that they were quite incapable of hardening, and in fact presented no quality of steel at all. It appears to me that if the Bessemer process could be successfully adapted to the production of the best kind of wrought iron, and were so used honestly and avowedly, it would be a much greater benefit to the engineering manufacture than flooding the market with a mass of the more pretentious material, too often of very doubtful character.

iron contains various substances in mixture; it is the object of refining to extract from it the larger portion of these impurities preparatory to its conversion into malleable iron.

Refining consists simply of melting the pig iron with coke or charcoal in an open hearth or "refinery furnace," supplied with an air blast so as to impinge on the melted metal and furnish an oxidizing atmosphere. This carries off a portion of the carbon, and at the same time removes a portion of the impurities, particularly silicon, in the shape of slag. The melted metal is then poured into cast-iron troughs kept cold by water, and the sudden chilling has the effect of converting soft grey iron into hard silvery white metal, the carbon which formerly existed in the shape of graphite, entering into perfect chemical combination. By this change the fluidity of the iron is reduced, and the subsequent puddling process facilitated.

In the refinery the blast answers a double purpose: it creates and maintains an intensely high temperature, fusing the crude iron with great rapidity, and it promotes the rapid oxidation of the impurities. The separation of these is further facilitated by mechanical subsidence, as they, being specifically lighter than the metal, float on the surface, and united with a certain portion of oxide of iron form liquid cinder.

The loss of weight in refining is considerable, particularly with common hot-blast pig iron, which is more highly charged with foreign ingredients than cold blast. The consumption of crude iron per ton of refined metal averages between 22 and 23 cwt. The consumption of coke is about 2½ cwt. per ton of pig iron operated upon. The weekly production of a refinery furnace is from 80 to 160 tons.

Refining is sometimes done with raw coal, but coke is generally preferred.

Puddling.

50. The process of puddling is carried on in a reverberatory furnace, in the bed of which the metal is melted by the action of flame, proceeding from a fire at some little distance away. Thus all contact between the metal and the solid fuel is avoided, and the necessity of blowing machinery dispensed with. The decarburization of the metal is effected chiefly by the strong current of air passing along with the flame, and caused by the draught of a chimney; at the same time a stirring action kept up by the men keeps the metal well exposed to the action of the oxygen. This admirable and most important invention was patented by Henry Cort in 1784.

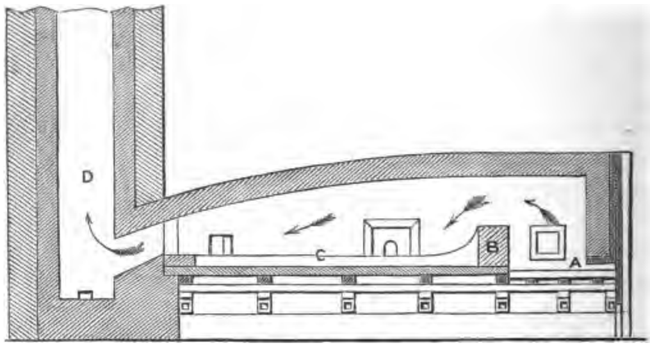
To aid the action of the air in the decarburization and purification of the metal, certain oxidizing fluxes are added, such as hematite, magnetic oxide of iron, forge scale, or molten slag, a silicate of protoxide of iron. According to the relative importance of the parts played by the air and by these fluxes respectively, the process may be either *dry* or *wet* puddling, the former being dependent mainly on the exposure of the metal to the action of the air, while in the latter (which is more generally known as the *pig-boiling* process) the slag and oxide of iron added are the most important oxidizing agents.

51. The following sketch shows a simplified longitudinal section of a puddling furnace, and will suffice to explain its general construction.

The fire is made at A, and is separated by a brick partition B from the hearth C, on which is placed the metal to be puddled. The flame passes from the fire-place to the lower part of the chimney D, and in its passage it "reverberates" down on the surface of the metal, creating an intense

heat, while the deleterious portions of the fuel are prevented from mixing with the iron. The heated current always has with it an excess of oxygen, which plays an important part in the conversion of the iron. There is a metal damper placed on the top of the chimney, with a handle within reach of the puddler, so that the draught, and the consequent action of the current on the metal, can be regulated to a nicety.

FIG. 2.



Puddling Furnace.

There is a balanced door on the side of the hearth C, which opens and closes with ease, and through which the puddler conducts his various operations on the metal within the furnace.

52. The process of puddling is susceptible of considerable modification, according to the nature of the pig metal employed, and that of the iron which it is desired to produce; but it may be generally described as follows:*—

The bed in which the iron lies is previously prepared by "fettling," as it is called, *i.e.* introducing the fluxing materials, and spreading or arranging them in a convenient

* Bauermann, chap. xv.

manner for their action on the iron. The metal is then introduced, with or without previous heating, and soon melts, spreading itself on the floor of the furnace in a thin sheet, thus exposing a large surface to the action of the air.

When complete fluidity is attained the puddler introduces a hooked bar or "rabble," and stirs the metal about, to incorporate the whole contents of the furnace well together. When the mixture is complete the reaction of the air and the oxidizing fluxes on the combined carbon becomes apparent by the escape of blue flames of carbonic oxide, and at length the whole surface of the metal begins to boil from the rapid escape of gas. This action is facilitated by constant stirring with the hooked bar, with which the puddler searches or sweeps every portion of the bed. The slag or cinder rises to the surface, and flows away by openings prepared at a suitable level. In some cases portions of the fluxing material are added during the puddling process.

As the carbon diminishes, the ebullition becomes less violent, and the metal, from its reduced fusibility, begins to stiffen, and malleable iron separates, or as it is called, *comes to nature*, in the form of bright points, which increase to spongy masses. These are manipulated with the tool and at last collected, by pressing them together till they are sufficiently coherent to be moved without falling to pieces, and are thus formed into roughly-spherical masses of from 60 to 80 lbs. weight each, called "puddle balls."

When one of these balls is ready it is drawn to the door with the tool, and removed from the furnace with a long pair of tongs with curved jaws. It is then either carried on a small truck or drawn along the floor of the mill to the place where it is to be treated by squeezing or "shingling."

The quality of the iron obtained is greatly dependent on the manipulation, but depends still more on the quality of

the pig operated upon. The greater the amount of impurities, especially sulphur and phosphorus, the longer will the puddling last, the greater will be the waste of metal, and the more uncertain the result.

In Staffordshire two hands (puddler and underhand), in a turn of twelve hours, work off from five to seven heats, the charge being from 4 to 4½ cwt. The loss of weight between the pig iron charged and the puddled bars produced from the balls (as hereafter explained) is from 7 to 10 per cent. The coal burnt amounts to between 20 and 22 cwt. per ton of puddled bars. The "fettling" materials required in the turn of twelve hours for keeping the bed in proper order are from 6 to 7 cwt. of "bull-dog" (a mixture of peroxide of iron and silicon, produced by roasting tap cinder, hematite or magnetic iron ore), and 2 to 3 cwt. of a soft red hematite, called *puddler's mine;* in addition to a certain quantity of black oxide of iron, or *mill scale* added to the charge.

In Scotland, where dark grey metal rich in silicon is "boiled" without being previously refined, only from four to five heats of 4 cwt. are made in the same time, and the loss of weight is from 15 to 18 per cent.

For the best Yorkshire iron, made near Leeds, a high quality of pig, mostly cold blast, and refined, is used; this is puddled in small heats of from 3 to 3½ cwt. each. Iron, when puddled in small quantities, is found to give better results, being freer from raw or unconverted metal. Nine or ten heats of best iron are puddled in ten hours. The consumption of coal is about 15 cwt. per ton of iron puddled.

The Welsh puddling and boiling furnaces turn out, according to Mr. Truran, upwards of 20 tons per week.

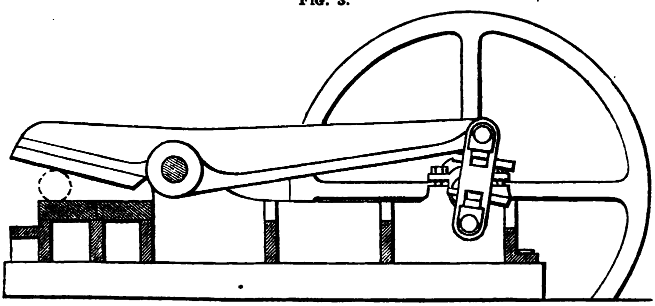
53. In order to lessen the great amount of labour involved in working the charge, various mechanical applications have

from time to time been proposed, in substitution for mechanical puddling, but none of them have been yet adopted to such an extent as to render a description of them necessary.

54. The puddle ball, as it comes out of the puddling furnace, consists merely of particles of malleable iron sticking together, but with large interstices, which are partly filled with the slag or cinder produced in the furnace along with the iron. Before this mass can take the shape of iron it has to be consolidated, and the slag driven out. This operation is effected either by *squeezing* or *hammering*.

55. Squeezing is used chiefly for the commoner descriptions of iron, for which it is most suitable on account of their tender texture, which would not stand the heavy blows of a large hammer. The machine ordinarily used for the purpose resembles a pair of jaws like those of a shark or crocodile, the lower one being solidly fixed like an anvil, and the upper one made to open and shut by machinery. The following sketch will show what the ordinary squeezer is like, and it will be sufficiently clear without any further explanation.

FIG. 3.



Squeezer.

The puddle ball, in its heated state as it leaves the furnace, is introduced between the jaws at their widest part, and the

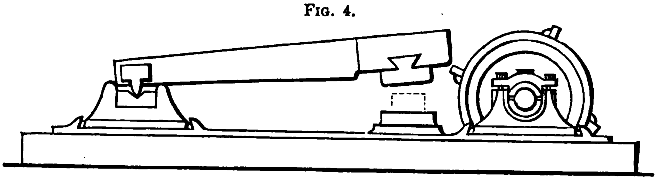
pressure squeezes the particles of the iron together and welds them, at the same time pressing out the slag, which runs upon the floor. As the mass becomes more consolidated it is pushed to a narrower part of the jaw opening, where the action is renewed with a more powerful pressure.

By this process the ball becomes transformed into a short thick cylindrical bar, about 1 or 2 feet long, and a few inches diameter; and while it is red hot, this bar is passed through grooved rollers, which draw it out into flat bars, usually about 3 or 4 inches wide and $\frac{3}{4}$ to 1 inch thick. These bars are what is called "puddled iron" or "puddled bar," and form the first stage of wrought iron manufacture.

Squeezers are frequently made automatic; and several kinds acting on this principle are used. The ball is dropped into one end of the machine, and then, by the action of rollers or cams, it is rolled or squeezed through a space constantly diminishing in width, at the end of which it comes out of the same form as it is brought to by hand labour under the ordinary squeezing.

56. For the better class of iron, the puddle balls are consolidated by *hammering* or shingling. This is done by large hammers called *helves*, or shingling hammers, of which the following sketch will give an idea.

FIG. 4.



Helve.

Helve hammers are generally made of several tons weight; they make between 70 and 100 strokes per minute, with a lift of between 16 and 20 inches.

In iron prepared by hammering, the puddle ball when brought out of the furnace is put under the helve, which is allowed to act on it by repeated blows, so as to thoroughly consolidate and weld the particles of the iron and drive out the liquid cinder. The mass is moved about between the blows, and may be given a long form and then rolled out, as in the case of squeezed iron, or it may be beaten into a flat cake, or any other shape that may be determined by the future process it is to undergo.

57. Steam-hammers have been employed in some mills; but for the iron-maker's purposes they possess no superiority over the common hammer. The power they have of giving great range in the force of the blow, though so very useful in forging, is of no use in manufacturing iron, as the metal is required to be hammered with the same force throughout.*

Mill Work.

58. Puddled iron, as has been already stated, is malleable iron in the first stage of its existence, and is hence often called No. 1 iron. In this stage, however, it is not fit for use in any way. In the first place the size and shape of the pieces are not such as are usable; and secondly, which is more important, the quality is not yet fully developed. The puddled iron must be still further *worked*, by hammering or

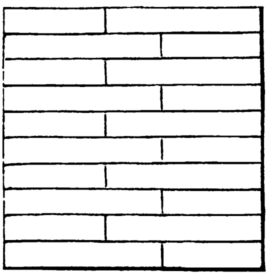
* A curious and instructive illustration of the use of the steam-hammer came to the author's notice some time ago. An engineer was induced to pay a considerable extra price for some rails in consideration of their being made from "hammered" iron. The author had occasion to inspect their manufacture, and found that the hammering was done with *steam-hammers* constructed for the purpose, and carefully regulated (as all steam-hammers can be) to give only a light blow. The quality was in reality just the same as the squeezed iron, or indeed rather worse, as the squeezers did force out the cinder, while the steam-hammer left it in.

rolling, before it fully acquires those peculiar properties (such as malleability, ductility, tenacity, and capability of being forged and welded) which characterize it as good wrought iron, and fit it for sale in the market. This repeated working is of much importance, as, with all wrought iron except that of very low quality, the more it is worked the better does the quality become.

The *mode* of working up the puddled iron varies much according to the quality of the material and the nature of the saleable article intended to be produced.

59. The most usual process is by piling and rolling. A number of bars of puddled iron, all cut to a uniform length, are packed together into what is called a *pile*, some 2 or 3 feet long and 6 or 8 inches square, the bars being so arranged as to break joint with each other, as in the following section. This pile being bound round with rod iron, to keep it together, is put in a furnace and heated to a welding heat. It is then passed between grooved rollers, which draw it out, at the same time reducing it in size, and subjecting it to a pressure that welds the bars together into one mass. Having passed through one groove it is immediately put again through another of smaller dimensions, and then through one of smaller dimensions still, and so on, continually being drawn out longer and of smaller section, and continually being subject to more pressure; either until the bar acquires the size intended, or till it becomes too cold to work further, when it has to be re-heated in a furnace to admit of further rolling.

FIG. 5.

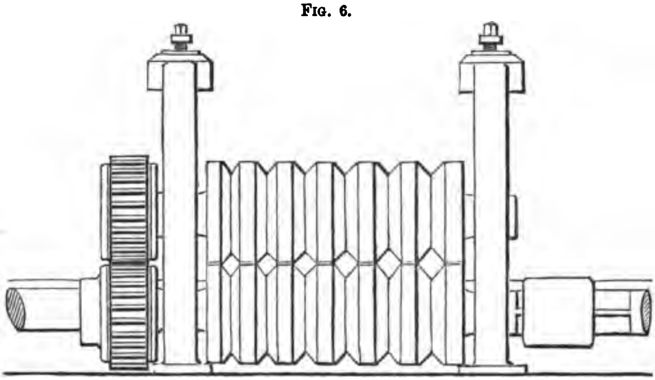


Pile for Bar Iron.

A pile partially rolled out, but not finished, or in fact any partially-worked short thick bar, is called a *bloom*, and the furnace in which such a bloom is re-heated is a *bloom-furnace.*

Often two pairs of rolls are used, one for the first two or three grooves, called *breaking down*, or *roughing*, or *blooming* rolls; the next pair for bringing the bar into its finished form, which are called *finishing rolls.* The following sketch shows a pair of finishing rolls.

FIG. 6.



Grooved Rollers.

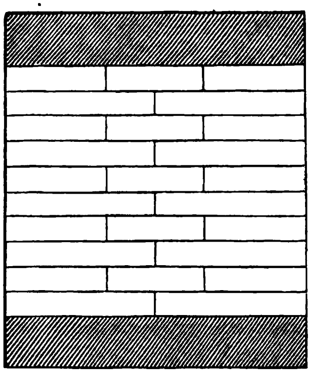
The lower roll is turned by the engine, and the upper roll is geared to it by pinions, so as to be caused to turn with it. The necks or bearings of the rolls turn in *housings* which are provided with screws, as seen in the figure, and by turning these the upper roll can be set nearer to or farther from the lower roll at pleasure, so as to diminish or increase the height of the grooves.

The invention of grooved rollers for the manufacture of iron is, like that of puddling, due to Henry Cort, who patented them in 1783.

60. With some classes of iron the puddle bar is first piled and rolled into bars of suitable size, which are called No. 2 iron, but which are not yet fit for use till they are again piled and rolled, forming then No. 3. Sometimes, with the better classes of iron, the first process of welding the pile together and reducing it to a bloom is done by hammering, or partly by hammering and partly by rolling; in short, the mode of working admits of great variety.

61. The operation of making a rail of good quality is as follows. A pile is prepared of about 8 to 10 inches square, with the bars arranged as in the following sketch. The shaded parts are No. 2 iron, intended to form the top and bottom of the rail, where the greatest strength and wearing quality are wanted, the intermediate space being filled up with puddle bars. The pile is brought to a welding heat, and is then first hammered under a heavy hammer, to weld and consolidate it, and next rolled into a square bloom of about one-half or two-thirds the sectional area of the original pile. This bloom is then re-heated and rolled down in grooved finishing rollers, each groove gradually approaching the form of the rail, until it acquires its perfect section and proper shape. The ends are then cut off square, while the bar is hot, with a circular saw revolving at a rapid rate, and which cuts red-hot iron almost as easily as an ordinary saw cuts wood. This gives the rail its proper length, and when cold

FIG. 7.



Pile for Rails.

it is straightened, and punched, if necessary, with the proper holes.*

By modifications of the piling and rolling process are produced all shapes and sizes of bar iron, angle iron, T iron, &c., &c., usually sold in the market.

62. *Plates* are made on a similar principle, but the pile is differently arranged, and is passed through, not grooved but flat rollers, first in one direction and then in another direction at right angles to it, so as to widen out the plate to a sufficient size, after which, when brought to the right thickness, it is cut to the exact length and width by shears.

63. The very best quality of iron, made chiefly in Yorkshire, is treated in a peculiar way from the commencement. The material used is carefully chosen, the pig is refined, and the puddling is conducted with special precautions. The puddled iron is shingled under a heavy hammer, and is not rolled into bars, but is beaten into flat cakes of about 12 inches across and 1½ to 2½ inches thick. These are broken into pieces by blows of a "guillotine"—a heavy ram falling from a considerable height—and the fracture is then carefully examined; for, notwithstanding the care taken in the previous processes, the uniformity of the result cannot be depended on. The examiners, by long experience, can judge by the appearance of the fracture which portions will make the best iron, and which only second best; as also which

* Mr. Truran (note to p. 227) deprecates the stipulation by engineers of any definite mode of manufacturing a rail, as he states they cannot be such good judges of what process will make a good rail as the manufacturers are. He consequently recommends that the process to be employed should be left to the ironmasters' discretion.

If there were any security that a trust of this kind reposed in the ironmasters would be faithfully carried out, I should quite agree with Mr. Truran's reasoning; but I am sorry to say that my long experience of the craft has not given me this degree of confidence in them.

kind is favourable for hard crystalline iron, and which for soft fibrous structure. The pieces are accordingly carefully selected, and each is put to its proper use. The slabs of puddled iron are piled together, and welded into solid masses under a heavy hammer. Hammering is always used in working this kind of iron to the greatest extent possible, the rolling being only a last process to give the proper shape to such articles as are of uniform section, such as tyres, best bars, &c., and for flattening out boiler-plates of this material.

64. For articles of complicated and special forms the slabs of puddled metal are piled together in suitable masses and then worked entirely under the steam-hammer, being re-heated and re-worked until they are brought into the required shapes. In this way are produced large cranked axles, for locomotives and for marine steam-engines, anchors, stem and stern posts for iron ships, and other large masses of wrought iron, which are called "large forgings."

65. Straight bars of large size, such as axles, large shafts, &c., which require to be tough and strong, are often made by a process called *faggoting*. A number of small bars of good iron are placed together and bound round like a faggot of sticks (whence the name); they are then brought to a welding heat in a furnace, and welded by blows of a heavy hammer; after which they are drawn down either by hammering or rolling, to the size required. If the original iron is good, axles so made are very trustworthy.

66. A good deal of wrought-iron work is made from what is called *scrap*.

In manufacturing wrought iron, it is always necessary to cut a good deal to waste; and these waste pieces, as also the

punchings out of holes, and old iron generally (if clean and good), are technically termed *scrap*. These are not thrown away, but are collected, sorted, and then made up into bundles, heated to a welding heat in a furnace, and hammered under heavy steam-hammers, first to weld the whole into a solid mass, and then to shape it into the required form.

Wrought-iron work made from scrap is often very good in quality, *if care has been taken in the selection and working;* but this care is very important, as if heterogeneous kinds of iron are mixed together, they will not properly combine; or if dirt and rubbish get in, of course imperfections will result. "Scrap iron" must therefore not be considered necessarily good iron.

67. Heavy armour-plates for ships and forts are an introduction of the last few years, and have required special provisions for their manufacture, on account of their great size and weight, some of them being 12 to 15 feet long, 3 or 4 feet wide, and many inches thick, and each weighing several tons. When iron armour was first thought of, it was formed by superposing thin plates on each other; but it was soon found that the strength increased in a more rapid ratio than the simple thickness, and hence it became desirable to get the plates as thick as possible. The first large armour-plates made were those of the 'Warrior,' 4 inches thick; they were made of scrap iron by hammering. The scrap was made up into bundles, these were welded into blocks, and several of these blocks being joined together formed small portions of the plate, which were at last welded into one.

Subsequently a firm in Yorkshire introduced machinery for making similar plates by rolling: puddled slabs were welded together and rolled into a large thin plate, and several

of these being laid one on the top of another, were heated in a large furnace and welded by rolling down to the desired thickness. The difficulty was in manipulating and heating such large masses of metal, and in constructing rolling machinery that would stand the great strain; but this has been successfully accomplished, and plates have been rolled upwards of 12 inches thick. Rolled plates have now nearly superseded those of the original hammered make, as they have been found to be softer, a quality of great importance in resisting the damaging effects of shot. At the same time the welding of the layers together is often found imperfect, from the difficulty of getting such large surfaces into a perfect welding condition, and in applying sufficient pressure.

68. The loss in making puddled into bar iron is generally about 15 per cent., partly caused by oxidation in the furnace, and partly by waste ends, &c., in rolling. The consumption of coal may be about 50 to 60 per cent. of the weight of the finished bars.

CHAPTER III.

ON THE MECHANICAL PROPERTIES OF IRON GENERALLY.

INTRODUCTION.

69. Before speaking of the various kinds of iron specially, it is necessary to say something generally about the *mechanical properties* which we may expect to find in the material, and which will much influence the use and application of it, in whatever form it be. Indeed, so important are these mechanical properties, that they may more correctly be considered as guiding and determining the structural use of iron; for it is chiefly by our acquaintance with these properties that we are able to decide to what structural uses, and in what modes the different kinds and qualities of iron may be applied to the best advantage.

By the mechanical properties of iron, I mean such qualities as the strength, the elasticity, the flexibility, the ductility, the hardness, the amenability to manufacturing processes, and so on; in short, all the qualities which develop themselves in the mechanical use of the material.

70. Now, you may become acquainted with these properties in two ways: by the *experience* of *others*, and by *your own observation.*

First, as to the experience of others. It is fortunate that the rapid progress of engineering science within the last thirty or forty years has prompted many able investigators to undertake inquiries and experiments on this subject, and to

publish their results for the benefit of practical men. And we consequently now possess, on record, a large fund of most valuable information as to the mechanical properties of iron. I shall have continual occasion during these lectures to quote authorities of this kind, and it is most desirable you should, when you have opportunity, refer to the original sources for fuller information.

But, valuable and extensive as are the published researches on the mechanical properties of iron, and necessary as it undoubtedly is that you should make yourselves acquainted with them, yet I must caution you that they will never supply fully the place of your own practical observation. Such of you as have any idea of engaging practically in the use of iron for structural purposes, may rest assured that however much you may read and refer, your ability to employ the material will be but very imperfect, unless you investigate, personally, its mechanical properties for yourselves.

I do not mean that you are hastily to set up as professional experimenters, for, laudable as it is to give to the public new data of this kind, and much as you should be encouraged to make known any new facts of importance that may come before you, yet you must always remember that to give experimental investigations the weight and authority that published works should have, requires an amount of care, time, patience, and expense, that few men in actual business can command. What I do mean is, that every person who has extensively to use iron for structural purposes should lose no opportunity of gaining personal experience, by actual observation, and by special experiment also if necessary, on the strength and other mechanical qualities of the material.

And it is not only as a matter of general information that this is necessary; it is required in the every-day working of a manufacturing establishment, for the reason that the

qualities and properties of iron vary so immensely, and are often so little to be depended on without careful and experienced judgment, that a personal and practical acquaintance with the subject becomes a necessary qualification.

The opportunities for this kind of investigation, on a scale sufficient for the purpose, are by no means costly or difficult to obtain; and I conceive that no manufacturing establishment where iron is extensively used ought to be considered complete without apparatus for testing its strength and other mechanical qualities.*

71. The first thing to be remarked about the mechanical properties of iron, is *the exceedingly wide variation* they present, in different varieties of the material.

I do not mean that cast iron differs widely from wrought, or wrought iron widely from steel; that is natural enough; but I mean that for the same genus of the material, we may find all sorts of varieties,—of tenacity, flexibility, elasticity, ductility, hardness, workability (to coin a word), and so on,—in different specimens.

To give you one example, the tenacity of cast iron has been found to vary from 4 to above 20 tons per square inch! And although this is an unusual case, you will see, when you come to follow the data I shall give you, that every property, in every class of material, varies over a very wide range.

On this ground I think there is some fault to be found with the manner in which the properties of materials in general, and of iron in particular, are usually expressed in books of reference. For example, if you refer to one of these

* An admirable establishment has lately been set up by Mr. Kirkaldy in Southwark, called the Testing and Experimental Works. It is provided with appliances on the most complete scale for all kinds of experiments on the mechanical properties of iron, and is open to the use of engineers on very moderate terms.

books, say for the tenacity of cast iron, you will perhaps find it stated that an inch bar will break with 16,476 lbs., or some such figure.

Now this, without explanation, is a mischievous fallacy; for it would convey, to a person unacquainted with the subject, the idea that the tenacity of cast iron is a definite amount, which can be determined and fixed to a nicety, than which nothing can be more untrue. Such a figure, at the best, could only properly be explained by saying that it was probably the *mean* of a certain number of trials of certain kinds of iron. But, really, such a datum is of the loosest possible kind, and of little or no practical use.

The first and most useful thing to be learnt about the properties of iron is that their properties will vary extremely, according to a great variety of circumstances, and that no general single mean value can be relied on as expressing anywhere near what you may find in the specimens you are dealing with.

If a mean is given, it ought to be fully understood to apply only to the specimens from which it is made. A *general* mean for all varieties of iron would have no proper signification at all, and could convey no useful practical idea.

On this account I shall endeavour rather to put you in possession of the *extent* to which the strength and other properties of iron may vary in different samples; and where it is possible I shall also try to direct your attention to the circumstances attending these variations, and on which they may, to some extent, depend. This is the real practical way in which the properties of iron must be learnt, to apply them properly for structural uses.

I now go on to make some general explanatory remarks in regard to the most important properties of iron, namely, the strength, stiffness, elasticity, ductility, and hardness.

TENACITY.

72. The most important mechanical quality of iron is its *strength to resist rupture.*

Rupture may be produced in several different ways; *e.g.*—

By *direct tensile force,* as, for example, pulling a bar asunder in the direction of its length.

By *crushing,* or compressive force, as in a column.

By *transverse* stress,* as in the case of a beam.

By *torsion,* as in the case of a mill shaft; and

By *shearing,* as in the case of a rivet.

And consequently we have to investigate the kinds of strength necessary to resist these various modes of rupture.

73. First, we have *tensile strength;* the cohesive strength which enables a bar of iron to *resist being torn asunder* when subject to a tensile force in the direction of its length. This kind of strength it is usual to call *tenacity.*

The stress suffered by such a bar is analogous to that on a rope in ordinary use, and it is a very common one in practice. The tie bar of a roof, the links of a chain, the lower member of a girder, are all subject to this kind of action.

74. The *tensile strength of a bar is usually assumed to be in direct proportion to the area of cross-section of the bar,* the stress being supposed to be equably applied all over the section.

* I have endeavoured, here and elsewhere, to adopt the new term "stress" in the sense given by Professor Rankine and other high English authorities on statics; but I confess I am exceedingly reluctant to give up the old engineer's word "strain," which appears to me to convey its idea so clearly that there must be little chance of expunging it from the practical mechanic's vocabulary.

Hence if

s = tenacity per square unit,
A = area of cross-section of bar,
Tensile strength of bar = A s.

75. In speaking of the strength of iron, it is customary to take the *inch* as the unit of measure; and therefore, in defining the tenacity of a certain quality of iron, we should give the amount corresponding to the strength of a bar of *one square inch in section*, or 1 inch square.

The unit of *weight* or *force* used in this country is sometimes the *pound* avoirdupois; sometimes the *ton* of 2240 lbs. Perhaps the former of these, the *lb.*, is the more correct and scientific; but it has the inconvenience of giving very large numbers in almost all estimations of the strength of iron, generally consisting of five figures at least; and I have found that these large figures convey a somewhat confused idea to the mind — they are difficult to realize, and still more difficult to remember. For this reason I have always preferred estimating the strength of iron in *tons*—which, indeed, is the universal custom with practical engineers. We almost always deal with quantities large enough to be expressed in units or tens of tons; and by the addition of one or two places of decimals any required degree of accuracy may be attained; while the data are very much simplified, and become much easier to recollect.

You will bear in mind, therefore, that when speaking of the strength of iron throughout this course of lectures, I shall (unless specially otherwise mentioned) always take the *dimensions in inches*, and the *force in tons*. Thus, when I describe a certain iron as having such a strength as to withstand, without breaking, a tensile force of 20 *tons per square inch*, you will have no difficulty in understanding the expression.

76. The tenacity of iron must be ascertained experimentally. There are no means of determining it *a priori*. A bar, or other piece of small size, must be subjected to actual tension, the force being increased till it breaks; the *breaking force* in tons, divided by the *area of the cross-section* of the bar, giving the ultimate tenacity per square inch of the material.

This operation, however, requiring the exercise of great force, must be done by a machine. A simple form of such a machine, with which excellent and useful work was done, will be found described in Mr. Kirkaldy's book, hereafter referred to. A much more elaborate and complete machine, intended for testing, not only the tenacity of iron, but also its strength to resist crushing or transverse or torsional strain, was devised by Major Wade at the instance of the American Government, for the purpose of testing the metals used in cannon founding. It is fully described in 'Reports of Experiments on the Strength and other Properties of Metals for Cannon,' published by authority of the American Government in 1856. A similar machine has been since erected at Woolwich Arsenal.

Testing machines will also be found described in the work of Mr. Styffe and elsewhere. The machines at Mr. Kirkaldy's testing works in Southwark are of great power and accuracy.

77. Some precautions are necessary in testing bars of iron for tensile strength.

In the first place, the line of stress must be parallel to the sides of the bar, and must *pass through the centre of gravity of the section* which is to be tested.

An excentric direction of the line of stress may often arise by careless formation of the trial bar. It is found that if the line of stress passes through *one edge* of the section instead of the middle, the bar will exhibit only one-third of

its proper strength, which shows the necessity of this precaution.

The sectional area of the bar, in the place where it is likely to break, must be carefully measured before any strain is applied. For if the metal is ductile, it will stretch, and will consequently *contract in area* before it breaks. The amount of this contraction is sometimes very considerable: it should be measured after the fracture, and a note kept of it.

I shall hereafter say more on this point when I come to speak of the experiments that have been made on the tenacity of wrought iron.

Then a necessary precaution is, that (in this as in all other modes of testing up to rupture) when the breaking point is approached, the weights should be added in small increments, allowing sufficient time between each for the weight to take its action. A bar will often stand a minute or two before it breaks under its ultimate load. Sometimes also a slight vibration or a gentle tap with a hammer is useful in determining the breaking point; but this must of course be done cautiously, or the bar will appear weaker than it really is.

STRENGTH TO RESIST CRUSHING.

78. The next kind of strength is the reverse of the former: it is the strength to *resist rupture by a crushing or compressive force*, as in a column, a strut, or an arch.

This is of quite a different nature from the tensile strength; for some forms of iron, which excel in the first, are very deficient in the second, while other forms are the contrary in both respects.

79. The compressive strength of every form of iron has therefore to be determined by direct experiment. And this

is done in a way somewhat analogous to the other, *viz.* by forming small pillars of the material, and subjecting them to a direct crushing strain, in the direction of their length, till they give way.

A machine used for this purpose by Mr. Hodgkinson, in his valuable experiments on cast iron, will be found described in the Blue Book of 1849.

The crushing test is also sometimes done by a *hydraulic press*, the ram being made to press directly on the sample cube or short pillar to be tested. This is a very simple mode of operation, but it involves some difficulty and uncertainty in the estimation. It is not easy, in the first place, to get accurately the real hydrostatic pressure which is being exerted at a given time. It is sometimes calculated by the opening of a weighted safety-valve, but it is not always a simple matter to determine accurately what the effective area of the valve is.

The pressure is better determined by weighting the plunger of the pump, but in this case there is also an uncertainty arising from the friction of the leather packing, which is pressed with much force against the plunger side. Then there is also a considerable friction from the leather packing round the large plunger, the value of which is difficult to ascertain, but which renders the nice determination of the pressure uncertain. It has been estimated that the friction of the plunger may sometimes amount to as much as 10 per cent. of the whole power.

The hydraulic press is often used for other kinds of testing, but the same objections will always apply. The determination of the force by actual weight is the much more positive mode.

80. The strength to resist crushing is, like the tenacity, usually taken to be proportional to the sectional area of the piece under trial.

81. This proposition, however, is not so generally true as in the former case. Mr. Rennie called it in question long ago as regarded bars of moderate size, his experiments leading him to suspect that the resistance to crushing increased in a higher ratio than the area. But Mr. Hodgkinson, on careful repetition of the experiments, did not find this opinion corroborated, and arrived at the conclusion, that in pieces of moderate proportions the strength was directly as the area of transverse section.

When, however, the transverse size of the specimen is *very much increased*, the law does not hold good. Suppose, for illustration, we take a cube of a soft material like lead, and subject it to compressive strain. If the sides of the cube are unconfined, the metal will freely bulge or ooze away, and the natural weakness of the metal will be evident. But if we confine the sides, so as to prevent this oozing away, we may make this soft material support any weight, like water in a hydraulic press.

Accordingly, if we have a very large area of surface (say, for example, a flat plate) exposed to compression, the inner portions will be confined by the outer ones, and prevented from oozing away; thus they will sustain much more than if they were unconfined, and as a consequence the resistance of the whole plate will be increased beyond that due to the natural strength of the material. A plate, for example, 12 inches square and 1 inch thick, would support much more than 144 times as much as a one-inch cube.

This is well known in practice; for it is a very common thing to put a sheet of lead under great weights, in order to give them an equable bearing on the surface below—the lead in such cases supporting much more, per square inch, than it would if in a small piece.

I have hitherto spoken of a soft metal; but if it is hard, we shall still have an analogous effect in large plates, the

centre portions being upheld and supported by the surrounding ones, and so prevented from crushing, as they would do if free.

However, in speaking of the compressive strength of iron in the ordinary way, we are accustomed to consider only pieces of such moderate size as not to come within this law, and therefore it is customary to consider the strength to be proportionate to the area.

82. It is very important that when specimens of iron are tested for compressive strength, their length should be properly proportioned to their diameter. If they are *too long*, they will be liable to *bend* under the strain, and will break with less than the true crushing force. If, on the other hand, they are too *short*, they will fall within the exception just mentioned as applicable to plates, the fracture will not be properly developed, and the metal will appear stronger than it really is.

The American experimenters give for the proper limits, that the length should not be less than twice, nor should it be more than three times, the smallest transverse dimension. Mr. Hodgkinson takes the limits between one-and-a-half and three times—agreeing pretty nearly with them.

Then, again, care must be taken (as in the case of tensile strength) that the line of pressure passes *parallel to the sides* of the specimen, and *through the centre of its section.*

Further, in testing for compressive strength, it is necessary carefully to watch for the *point at which rupture takes place;* and to determine this accurately requires some experience, as different qualities of material behave differently under extreme strain. A hard metal, for example, with little ductility, will *yield* but little, under the progressive strain, but will crack and fly to pieces suddenly. On the other hand, a softer and more ductile metal will give way consider-

ably as the pressure increases, and change its shape so much before actual fracture as to render it difficult to determine where the point to be termed *destructive crushing* really lies.

Transverse Strength.

83. Another way in which the strength of a material is shown is by resisting rupture from *transverse* stress.

This is the nature of the strength which comes into play when a single bar of iron is used as a beam; being laid horizontally on supports at the ends, and loaded in the middle.

There is undoubtedly a connection between strength in this direction and the simple tensile or compressive strength; and Tredgold, one of the earliest investigators of the strength of iron, endeavoured to deduce one from the other; but not being in possession of all the elements necessary for the calculation, he got very much wrong.

84. It is always the custom in practice to determine this kind of strength by direct and independent observation; and to do this is the simplest of all experiments. We have merely to take a bar of rectangular section, support it upon two props; and load it in the middle till it breaks, noting carefully all the dimensions, and the ultimate breaking load.

85. It is necessary then to put the result in some *general form comparable with other results*, and this is done as follows:

The principles of mechanics teach us that in rectangular bars of similar material the breaking weight ought to vary directly as the breadth, directly as the square of the depth, and inversely as the length between the supports. If then

$$\left.\begin{array}{l} b = \text{breadth} \;\; .. \;\; .. \;\; .. \;\; .. \\ d = \text{depth} \;\; .. \;\; .. \;\; .. \;\; .. \\ l = \text{length between supports} \end{array}\right\} \text{all taken in inches,}$$

W = breaking weight in tons, hung on the middle,

$$\text{Then } W = A\,\frac{b\,d^2}{l},$$

where A is a constant depending on the strength of the material.

Therefore, whatever the dimensions of the bar tried, the constant A, being found such a value as will satisfy the equation, will express the *transverse strength of the material* in a way to enable it to be compared with experiments on any other bars.

Strength to Resist Rupture by Torsion.

86. The fourth kind of strength is that which resists *rupture by torsion;* the best example being a *mill shaft* in machinery, where the power is applied tangentially at one end to move a tangential resistance at the other.

This also is usually determined for any given material, by direct experiment.

87. The way the strength is expressed, so as to compare with other results, is as follows :—

The resistance to torsion of a circular shaft varies as the *cube* of the diameter; and the amount of twisting force is expressed by what is called its *moment, i. e.* its amount in a tangential direction, multiplied into the perpendicular or radial distance of the tangential line from the centre round which the shaft turns. If therefore M = moment of twisting force sufficient to break the bar,

$$M = Bd^3,$$

where B is the constant that expresses the *strength of the material to resist fracture by torsion.*

Strength to Resist Rupture by Shearing.

88. This is a kind of strength which, though entering largely into modern theoretical calculations, has been so little investigated experimentally, as scarcely to admit of special mention here. Its principal practical application is in

riveting, the rivets in iron structures being liable to be sheared off by a strain at right angles to their axes. In this case, experiments seem to have warranted the assumption generally acted on, that the strength to resist shearing varies directly with the sectional area, and is about the same in amount as the longitudinal tenacity.

Stiffness and Elasticity.

89. After the strength of iron to resist rupture, the next important property is that which affects its change of form. This involves the inquiry how much the material will *bend*, *yield*, or *give way*, under a given strain applied.

A great variety of terms are used by mathematicians in treating of this subject; such as stiffness, pliability, extensibility, compressibility, flexibility, elasticity, resistance, and so on. But as my object now is entirely practical, I shall endeavour to confine myself to those which have a directly practical signification, and the meaning of which I will try to make clear in a practical point of view.

If we attach one end of a bar of iron to the ceiling, and hang a weight to the other end, the bar will stretch. The property which enables it to do so is called *extensibility*.

If we rest one end of the bar on the floor, putting it upright like a column, and lay a weight on the top, it will shorten or compress. This is due to *compressibility*.

We want, however, one word to express both these qualities,* and in default of a better we may use the word "*pliability*," this representing, so to speak, the willingness of the bar to extend or to compress when a force is applied in either direction. The reverse of this, *i.e.* the *reluctance* of the bar to

* The Germans have coined a very useful and comprehensive word *Verschiedbarkeit*, to denote that property of a body in virtue of which it can assume any kind of change of form, whether resulting from tension, compression, flexure, or torsion.

alter, I shall call stiffness; and it is the stiffness of iron we shall have to investigate.

90. Now if the straining force is small, the bar will, on the force being removed, tend to return to its former length; this tendency, as you know, is termed *elasticity*.

If the bar does return fully and perfectly to its original length, the elasticity is said to be *perfect*. If it does *not* so return, but retains, after the weight is removed, a permanent alteration (or, as it is practically called, a *permanent set*), the elasticity is *imperfect*.

91. The theoretical nature of elasticity is a complicated subject, but we may assume, in practice, that the elasticity of most bodies is sensibly perfect so long as the *stress does not exceed a certain limit*. If it is carried beyond this limit the elasticity fails, and a permanent set will result.

This point is called the *limit of elasticity*, and it plays a very important part, both theoretically and practically, in the strength of materials.

The limit of elasticity has been described by Professor Reilly as that point beyond which an increasing permanent set is observed on repeated re-applications of a load of the same intensity. Or, as another definition, it is that point beyond which the deformation ceases to be approximately proportionate to the intensity of the load.

The limit of elasticity is generally much below the point of fracture. It varies exceedingly in different bodies; in tempered steel, for example, the range of perfect elasticity is very large; in wrought iron it is much less; in cast iron less still; in lead almost null. In iron the relation of the limit of elasticity to the breaking weight depends not only on the chemical constitution of the material, but also on the manipulation to which it has been subjected. Mr. Styffe

found it vary from about 0·5 to 0·7. In some few specimens it was as high as 0·8.

Now as the alteration of the elastic power of the body is a step in the road towards rupture, and as in many cases when this limit is distinctly and sensibly passed, the damage increases in a fast ratio, it follows that in all iron structures the dimensions should be such that the stresses on the various parts will, under the greatest possible loads, remain within the elastic limit, so far as this can be determined. Further explanation on this point will be given under the heads of the different kinds of material.

The determination, by experiment, of the limit of elasticity for a given material is a very troublesome and uncertain process, it being so exceedingly difficult to determine the point where permanent set begins. Indeed it often happens that what may be called a false permanent set may be observed, inasmuch as it is found (Styffe, Art. 11) that an extended bar does not, on the removal of a force clearly within the elastic limit, instantaneously resume its original length, but a so-called secondary action ensues, *i.e.* the bar at first assumes a length slightly different from its original dimensions, and returns only by degrees to its primitive length. Hence the limit is hardly capable of being fixed with exactness, it can only be approximated to. A margin should always be left in application, to cover deviations on the wrong side of the approximate limit.

Mr. Styffe treats this subject at considerable length. He alludes to the practical definitions given by many physicists, which he objects to as arbitrary and uncertain, and he proposes another one, which he considers preferable. For this, his work, Art. 18, may be referred to.

The limit of elasticity in metals may be raised by cold hammering, cold rolling, wire-drawing, or by other analogous manipulations, which tend to change the molecular con-

stitution; and this method of increasing the elasticity is often taken advantage of practically by workers in metal. Mr. Styffe found that the limit of elasticity of a sample bar was raised about one-third by repeated experimental stretching.

If a bar be stretched several times in succession by a load sufficiently great to produce permanent elongation, it is found that this load causes each time a new elongation, although its value, other things being alike, becomes each time less than at the previous experiment.

92. It is a condition of perfect elasticity that the body will stretch an equal quantity for every equal increment of force added; or, in other words, that the amount of *extension* shall be proportional to the *force applied*. Dr. Hooke laid down this law under the well-known axiom "*ut tensio sic vis*," which is taken as always practically true within the limits under which the elasticity remains unimpaired.

It is also a further condition that, always under this limit, the same amount either of extension or compression will be produced by the same force.

Now in the estimation of the stiffness of iron, which we shall hereafter have to consider, it is customary always to assume that the strain *is kept* within the limit of elasticity, and that within that limit the elasticity is perfect. This is not absolutely true with all kinds of iron, but the exceptions will be noted when we come to them.

The problem, then, of estimating the stiffness, or its inverse, the pliability, becomes to ascertain how much (always within the limit of perfect elasticity) a bar of iron will stretch or compress under a given strain.

This must be found by experiment. Let

l = length of bar in inches,
a = its area in inches.

And suppose that by applying to its end a longitudinal force = W in tons, we produce in it an extension or compression = λ. Then the function $\frac{W\,l}{a\,\lambda}$ is constant for the same material, whatever the dimensions of the bar or the force applied, and therefore represents the *stiffness* of the material.

93. It is usual to call this constant the *coefficient or modulus of elasticity* (a name given to it by Dr. Young); but this does not seem to be a correct name, as the constant has nothing to do with the *limit* of *elasticity*, which is the only measurable thing belonging to that property.

It is more correctly the *modulus or coefficient of elastic stiffness*, being the reciprocal of the longitudinal pliability. It is always designated in modern mechanics by the Roman capital letter E.

94. The elasticity and pliability of iron are also shown when a bar is weighted transversely.

It will *bend* under the weight, and if the strain does not exceed the limit of elasticity, it will recover itself when the load is removed; if this limit is exceeded, a permanent distortion will be produced. This bending, in the case of beams, is called *deflection*, and the modulus of elasticity enables us to calculate it for any given size and form of beam.

The same qualities are also shown when a bar is submitted to torsional strain, as in the case of a shaft in machinery. The shaft will twist, and will recover its straightness when the force is removed.

Ductility.

95. If the force longitudinally applied to extend a bar is carried much beyond the elastic limit, the property of

ductility comes into exercise. If the bar is very ductile, it will elongate and stretch considerably before it breaks; in some very ductile materials it would scarcely break at all, but would go on stretching almost as long as the force could be continued.

On this principle the length to which a bar will stretch before it breaks furnishes an indication of the ductility, which can be estimated by careful measurement when the iron is tested for tenacity.

96. This element is of much importance in estimating the value of iron to resist strains.

For supposing we have two kinds of iron of equal tenacity, *i. e.* that an inch bar of each will break with the same weight. But suppose one of these bars is very brittle and hard, and will break without extending scarcely at all, while the other will *stretch considerably* before it breaks; it is evident that the second bar will be far *safer* to use than the first, and consequently that the *tenacity*, taken alone, is not a sufficient test of the effective strength of iron for structural purposes.

This consideration, however, obvious as it is, has often been lost sight of. For example, in the case of the unfortunate iron ship 'Royal Charter,' which went to pieces, with such an awful loss of life, suspicion was aroused that the plates were not so good as they ought to have been, and they were tested accordingly. They were found of fair average *tenacity*, and were therefore pronounced good; but it may have happened that, in spite of this tenacity, they were hard and brittle, which would be a worse defect under such circumstances than weak cohesive strength, as it would almost ensure the breaking up of the ship under heavy concussions.

Be this how it may, there is no doubt whatever that large quantities of plate iron in the markets, although of fair

tensile strength, is much wanting in ductility, and I cannot therefore too strongly impress on you the importance of this quality, particularly for purposes where the iron is subject to sudden strains.

97. We are indebted, first to M. Poncelet, and subsequently to Mr. Mallet, for an endeavour to *combine* the *tenacity and ductility* in one expression, by stating the quantity of *work* or mechanical *power* exerted to break a bar.

Work, as you will probably know, is the expression used in modern engineering mechanics to denote the compound function of force applied, $\times$ space through which this force acts.

Suppose we have a bar of ductile iron attached, as before, to the ceiling, and weighted at its lower end, so as to put it in tension. And suppose we gradually increase the weight from 0 till the bar breaks with a weight $=$ W.

And further, suppose that at the time of rupture the bar has extended a quantity $= \lambda$, then the quantity of *work* developed in this process is assumed to be represented by the function $= \frac{1}{2}\,W\,\lambda$.

Now as a standard of comparison it has been proposed to give, in regard to any iron, the *quantity of work necessary to break a bar one foot long and one inch square*, which is found by multiplying half the ultimate tenacity by the ultimate elongation in 1 foot of length.

This should be stated, not in tons and inches, but in *lbs.* and *feet*, it being customary to express *work* in the unit which is called a foot-pound, *i. e.* 1 lb. moved through a space of 1 foot. It will be easy to convert our data into this form.

The quantity here alluded to has been called Poncelet's or Mallet's coefficient, and it gives, as I shall hereafter explain, the best indication of the *toughness* of iron (which is a compound of the tenacity and the ductility), and may therefore

represent the power of the iron to resist blows, concussions, and sudden strains.

Hardness.

98. Another quality of iron, of great mechanical importance as regards its structural use, is its *hardness.*

The well-known popular expression "*as hard as iron*" would lead to the supposition that all iron was very hard; and so it is, as compared with many other metals. But, really, it is very varied in this particular, some varieties being almost as hard as precious stones, while other kinds are as soft as brass.

And it happens that these different degrees of hardness are conveniently adapted to the different uses the material is put to. In *tools*, for example, a high degree of hardness is desirable, as it also is in all parts of machinery, and other articles subject to *wear;* while, on the other hand, hardness is a disadvantage in articles which have to undergo the operations of the workshop, as turning, boring, drilling, or planing. For this purpose, the softer the material is the better.

99. The hardness of iron has been one of the most important considerations entering into the use of iron for the *armour plating* of ships of war, and occupied much the attention of the Committee who some years ago investigated that subject. For, contrary to all previous expectation, hardness, so far from being a desirable quality for armour plates, proved to be the worst defect they could have; and all the efforts of the Committee were directed to induce the manufacturers to supply iron of the *greatest possible softness*, in which, by perseverance, they have tolerably succeeded.

100. There have been but few systematic attempts to *determine* and *define* the hardness of different kinds of iron.

Workmen who have to operate on the material can estimate it practically with tolerable precision, by its behaviour under their tools. There are many signs by which hardness and softness are known to persons accustomed to the material, and a simple touch with a file will give, to a practised hand, something of an indication.

But I am not aware that any definite *scale of hardness* was ever adopted for iron, or any means devised for accurately testing it, before the American experiments on cast iron I have already mentioned.

The mode the experimenters adopted was by *pressing a pointed punch* with a given force upon the surface of the metal, and measuring the capacity of the indent made. The most convenient form for the punch was found to be a pyramid, making an indent of a corresponding shape, the content of which could be easily estimated by measuring the longest side. The force used was 10,000 lbs.

There appeared some difficulty in defining a standard of hardness, and, in default of a better, the experimenters took, as unity, a certain indentation rather greater than they could produce in the softest metal (bronze) used for cannon; the hardness of other specimens was then measured by the *inverse* proportion of the indentation made in them.

Thus the standard indentation being 3·33 cubic tenths of an inch, if in a certain iron the indentation was found = 0·33 tenths, it would be described as of a hardness = 10. If 0·165, it would be 20, and so on.

The Iron Plate Committee contemplated, at one time, adopting a similar kind of test, but they found the practical indications given by the plates, when fired at, were usually sufficient to determine their comparative quality.

CHAPTER IV.

CAST IRON.

101. Cast iron is the *first form* in which we get iron, according to the usual English process of smelting. The produce of this process is exhibited in the shape of rough bars or ingots, called "*pigs*," the material itself, in this stage, being called " pig iron."

This material is fusible under a moderate heat; and by melting these pigs, and casting them into moulds, we obtain what are called *castings*, in the material called *cast iron*.

102. It is not, however, all pig iron which is fit for this use; for pig iron is also used for the manufacture of malleable iron, and the qualities made for the two purposes are quite distinct from each other.

The kind intended for making cast iron, is called *foundry pig*, and it is only with this variety we have now to do.

103. The process of melting the pig and casting it into the required shapes is called *iron founding* (from the French *fondre*, to melt), the place where it is done is an *iron foundry*, and the person who does it is an *iron-founder*.

104. The iron is melted in a vertical furnace called a *cupola*, which is, in fact, a miniature imitation of a blast furnace. It may be from 8 to 15 feet in height, and 2 to 4 feet square, and it is usually built of iron plates, and lined with fire-brick, to withstand the heat. It is filled with coke, which is kept in a high state of incandescence by a blast of

air, introduced through one or two twyers some distance from the bottom. The pig iron is broken into small lumps, and is thrown on the top of the incandescent fuel, when it soon becomes melted and drops down through the interstices of the coke to the bottom part of the furnace, where it collects till it is wanted. To complete the parallel with the blast furnace, a little limestone is often added as flux, to purify the iron by combining with the earthy matters contained in the pig, and forming a vitreous slag. At the bottom of the cupola is formed a small tap-hole, which is usually stopped with sand or clay; when sufficient iron has melted, this hole is opened or "tapped" and the metal flows out, being caught in large bowls or ladles, by which it is carried away for use.

By proper contrivance the contents of several cupolas may be used together to form a large casting; but in establishments where very large articles are required to be made, the iron is melted in larger quantities in a reverberatory or air furnace specially constructed for the purpose.

105. The moulds are made in sand, of a kind which will adhere together in the shape it is pressed into. A *pattern* or *model* of the article required must be made, generally in wood; the sand is rammed upon this, and when the pattern is withdrawn, a mould of it is left in the sand; the melted iron is then poured into the mould, a casting is produced having the shape of the original pattern. The pattern must be about one per cent. larger than the intended size, to allow for the shrinkage of the metal in cooling, and many precautions are necessary in forming the pattern to make it "leave the sand," and otherwise to facilitate the operation of moulding. These are difficult to describe, and are better learnt by a visit to an iron foundry. Holes in the casting are made by inserting in the moulds pieces of dried sand called *cores*.

In some cases of large castings, the moulds, instead of being formed in loose sand from a pattern, are built up in *loam*, a mixture of sand and clay, which is then dried, preparatory to the admission of the iron.

When cold the castings are cleaned from the sand, and the superfluous pieces chipped off with a chisel, when they are ready for delivery.

106. The process of iron founding comes strictly within the province of the engineer. The business of the iron producer ends, in the case of cast iron, with the delivery into the market of the *pig* in its various qualities. It is the duty of the engineer to make himself acquainted with the whole process of its conversion into castings, as there are many circumstances attending this process which directly influence the use and application of the material.

107. The first thing is the quality of the pig. *Foundry pig iron* is distinguished from that intended for making wrought iron, by containing more graphitic carbon in its composition, and being softer and more open in the texture, and more dull and grey in the colour.

There are three kinds of foundry pig, distinguished in the trade as Nos. 1, 2, and 3, respectively. No. 1 is the largest in texture, and is generally the dearest; Nos. 2 and 3 are successively of closer grain, and cheaper.

Now the first duty of the founder will be to determine what kind of iron he will use to make his castings, and in this he will be guided by the nature of the object to be made, and the purposes it is to serve. We shall see as we go on that cast iron is subject to *very wide variety* in all its mechanical qualities, and the founder should aim to give his casting such qualities as it may specially require. In some castings *strength* may be the paramount object; in others,

hardness may be more important; in others, precisely the reverse, *softness;* in others, *fineness of surface;* and so on, all which varieties may be obtained by the skilful maker.

For this purpose the elements of his choice are threefold, *viz.*:—

1. The different qualities of the three numbers of pig.

2. The differences, even in the *same number*, made by different makers.

3. The differences which may be obtained by different manipulation in the foundry.

The two first of these I may dismiss briefly.

In regard to the quality of the different numbers respectively, the general rule is that No. 1 pig is usually soft and tender, while Nos. 2 and 3 are progressively harder and stronger.

But secondly, the same number of pig will have very different qualities as made by different makers. To deal with this fact fully and successfully in practice, can only be accomplished by the experience of almost a life-time passed in the foundry trade.

108. But the third cause of variety in the quality of castings, *i. e.* the variety produced by different modes of treatment of the material in the foundry processes, comes more legitimately within the discussion of the engineer. And these differences are of several kinds.

109. First:—the very process of simple melting alters the quality; for if we take a piece of simple pig iron, melt it, and run it into a mould, we shall find that the resulting casting by no means corresponds in quality with the pig from which it was made.

The process of melting eliminates some of the impurities, and thereby improves it in strength and makes it harder.

Pig iron, being the first produce from the blast furnace, is called *first melting*. When this is re-melted and cast, it becomes *second melting*. When further melted and cast it is termed *third* melting. It is found that, as a general rule, second melting is better than first; and third better than second.

It is essential to bear this in mind; for it sometimes happens that in the iron districts, ironmasters will, to save expense, make castings by running them direct from the blast furnace, *first melting*; and where there is danger of this being done, the engineer ought to stipulate that the castings shall be made from the cupola, second melting, and not from the blast furnace.

Sir Wm. Fairbairn attempted to ascertain to what extent this principle would hold good. He procured a certain description of pig irôn, and melted it *eighteen times over*, preserving each time samples for trial, in the shape of a bar of certain size, and a cube. The bar was tested for transverse strain, with these results:—With the first melting, it broke with 490 lbs., and its strength gradually increased till, at the twelfth melting, it carried 692 lbs.; it then diminished again, till at the eighteenth it broke with 312 lbs.

The cube was tested for *crushing*, and it gave as follows:—

1st melting	.. ..	44 tons
12th ,,	.. ..	73 ,,
14th ,,	.. ..	95 ,,
18th ,,	.. ..	88 ,,

showing a somewhat similar kind of result, though more irregular.

Independently of the improvement by the simple fact of re-melting, it has been found that the *length of time during which the iron continues in fusion* has an influence on the quality, the strength improving as the iron is left longer in the furnace.

I believe these facts are explained metallurgically by the conversion of the grey or graphitic cast iron more or less into the white variety, by the loss of its free carbon, the latter kind being naturally stronger. And it has been pointed out that the degree in which iron is improved by repeated meltings, may depend much upon the kind of iron employed; and also to some extent on other conditions of casting.

But granting that in some cases the strength might increase up to the tenth or twelfth meltings, there are practical considerations which prevent anything like so large a number being used.

In the first place the iron, although it may become stronger, becomes also harder and more brittle by these repeated meltings, which would of itself be a disqualification for most purposes to which castings are applied.

And then again, there is a certain necessary waste in every melting, which would render its frequent repetition too expensive.

In practice it is seldom found advisable to carry it beyond the *third;* indeed the majority of castings are made merely *second.*

110. But the most important variation which the founder is able to make in the treatment of given materials is by *mixing them.* It is found that the mixtures of different kinds of pig, melted together, will produce greatly improved results in the quality of the castings. It is not only the mixtures of different *numbers of pig,* but also by mingling the produce of different makers; and it is, moreover, found beneficial to mix different *meltings* together, which is done by the addition to fresh pig iron of what is called *foundry scrap,* *i. e.* broken castings, or other waste pieces resulting from previous foundings.

111. Then differences of quality in castings will arise from their position in the mould. The portions of a casting lying at the bottom of a deep mould, and which are consequently subject to a greater hydrostatic pressure of the fluid metal, are more solid, and of higher specific gravity than the upper portions, and less liable to flaws and air-holes. Whether or not the metal is actually stronger, appears uncertain, but the advantages of soundness and density are of considerable value.

There is also some difference due to the position of the mould. Bars cast horizontally will differ from those cast vertically, and the preference is generally given to the latter position, as giving greater hydrostatic pressure.

112. Further, the quality of a casting will depend on the *mode in which it is cooled.* Rapid cooling, to a certain limit, appears to be more favourable to strength than slow cooling while it at the same time makes the metal harder.

113. It is possible indeed to give an extreme hardness to the surface of castings by very rapid cooling. This is done by a process called *chilling*, in which the melted metal is poured into moulds of iron, the coldness of which (owing to its rapid conduction) chills the surfaces, and makes them extremely hard, giving them at the same time a peculiar fine white texture.

The conversion of soft grey into hard white cast iron by sudden chilling, is explained by the passage of carbon from a free or graphitic state to a state of perfect chemical combination—a change which has been already alluded to in speaking of the production of the metal. It is not all iron that will take this process, but the founders who use it become aware by experience what pig to employ.

The process of chilling is very useful in many cases where

a hard surface, to withstand wear, is required to be given to one portion of a casting, the remainder being kept in the ordinary condition.

114. The Americans, in the manufacture of the huge cast-iron guns for which they have been so famous, have introduced an application of the cooling process which they have found of great value. The usual plan of making cast-iron guns is to cast them solid, and bore them out. In this mode the cooling of the metal commences on the outside, and gradually proceeds inwards; and there is little doubt that in this way the *exterior* becomes more perfect and stronger in its texture than the interior—the *skin*, as it is termed, being always considered the best part of the casting.

But it being clearly of the greatest importance to have a good quality of metal in the interior of the barrel, the Americans have reversed this process. They now cast their guns *hollow*, and cool the *interior* rapidly by allowing water to circulate through the core; while at the same time they keep the exterior *warm* by artificial heat, so as to protract its rate of cooling.

It has been found, by comparative experiments on guns cast according to the two methods, that the hollow ones greatly surpass, in strength and endurance, those formed on the solid plan.

115. As an example of how much improvement may be made in the quality of cast-iron articles by attention to the foundry processes, I may quote the statement of the American reporters, that the mean tenacity of the metal of cast-iron guns cast in the Government foundries in 1851, was greater than some ten years before by above 60 per cent.; this result being attributable, not in the least to the introduction of any new material, but to greater study and care in using it to the best advantage.

116. When cast iron is cast in large masses, it is found that it crystallizes differently in different portions of the mass; the external surface, which cools first, is close and strong, but the interior is coarser-grained and weaker, and often (in very large masses) spongy and unsound.

Hence in small castings, in which the external surface bears a large proportion to the whole cubical content, we shall have a greater average strength than in large masses, where the weakening influence of the interior is more perceptible.

I shall give striking instances of this in speaking of transverse strength.

STRENGTH.

117. I now proceed to tell you what is known about the strength of cast iron, distinguishing the strength to resist rupture in the four ways by — Tension — Compression — Transverse loading—and Torsion.

118. First, as to the *tensile* strength or tenacity of cast iron.

Cast iron had been long in use before any experiments were made to ascertain its resistance to direct tensile strain. About the commencement of the present century it was first used for beams; and it was the application of the material by engineers in this way that induced Tredgold to write, in 1822, his celebrated book on the Strength of Cast Iron. Tredgold mentions a few direct experiments on the tensile strength of cast iron, but he appears to have had no confidence in them, being somewhat contradictory and uncertain; he therefore attempts to deduce it from the *transverse strength*, which is pretty well known, and which indeed he experimented on himself.

When a bar is supported horizontally at the two ends, and loaded in the middle, if we suppose the elasticity perfect, there will be a certain relation between the weight on the bar

and the tensile stress on a given fibre at the lowest point at the middle of the beam.

On this assumption therefore Tredgold calculated, from the *breaking transverse weight*, what he conceived would be the ultimate tensile longitudinal stress. He assumed that the position of the neutral line remained fixed up to the breaking point; and in this way he made out the ultimate tensile strength of cast iron to be 18 to 22 tons per square inch.

Mr. Eaton Hodgkinson many years afterwards pointed out the error Tredgold had made. He showed that in consequence of the imperfect elasticity of the material, and its departure from the analogy Tredgold had assumed, the neutral line, at the time of fracture, instead of remaining in the middle of the section, came very near the top, and that therefore the whole calculation was wrong.

He suspected that Tredgold's estimate of the tensile strength was very much overrated, and he instituted a series of *direct* experiments to test it; which are reported in vol. vi. of the Reports of the British Association.

119. These experiments were made by directly pulling asunder bars of from 1 to 4 square inches in sectional area, and cast from several different kinds of iron.

The highest tried gave an ultimate tensile strength of 9·75 tons per square inch; the lowest 6 tons; the mean of all about 7·37 tons; being only about one-third the amount given by Tredgold.

Previously to this, however, the tensile strength had been directly tested in France, the results being given by M. Navier as follow:—

Maximum	9·08 tons
Minimum	5·09 „
Mean	7·19 „

The Iron Structure Commission of 1849 instructed Mr.

Hodgkinson to try a further series of experiments on the tensile power of cast iron, which are recorded in their report.

He pulled asunder eighty-one specimens of seventeen different kinds of cast iron, each specimen having about 3 or 4 inches of cross-section.

The highest he records broke with 10·5 tons per square inch; the lowest 4·9 tons per square inch; the mean of the whole gave 6·8 tons.

120. I have already mentioned the valuable experiments made by the Americans on cast iron as a material for cannon.

Among these were several direct trials of its tensile strength, which were so arranged as to show particularly the influence on the strength of the foundry process of re-melting, applied in various ways.

By testing samples of the same iron, first and second melting, it was found that while a certain pig iron, first melting, had only a tensile strength of 5 tons per square inch, by re-melting it, and allowing it to remain six hours in fusion, the strength was increased to above 11 tons; and by melting it a *third* time, the strength was increased up to (34,728 lbs. =) 15·5 tons.

Another kind of iron, tested on the *second* fusion, was found to have a strength of (15,729 lbs. =) 7 tons; but on melting it a third time, and keeping it eight hours in fusion, the castings made from it were found to have a strength of (34,599 lbs. =) 15·4 tons.

It was found that some advantage was due to keeping the metal for some time in fusion in the furnace before casting. A certain iron, second melting, was tested by tapping the furnace at different periods, and the strength was found:—

		Lbs.		Tons.
After ½ hour	.. .. ..	15,729	=	7
„ 2½ hours	.. .. ..	21,995	=	9·8
„ 4½ „	.. .. ..	27,852	=	12·4

The same iron was again re-melted and gave :—

	Lbs.	Tons.
After 1 hour	30,607 =	13·6
„ 3 hours	32,978 =	14·7
„ 4 „	34,599 =	15·4

It was also found that the specific gravity went on increasing along with the tenacity, so as indeed to form, to a certain extent, an index of the strength.

But the American experimenters found that all kinds of iron were not affected by these processes in the same degree; some kinds, which exhibited a favourable quality in the rough pig, were only slightly improved, and some seemed even impaired. The improvement seemed to take most effect with No. 1, soft grey pig iron.

The highest tenacity recorded in these experiments was (45,970 lbs. =) 20·5 tons, being samples cut out of a 10-inch Columbiad gun, cast at Fort Pitt Foundry. The sp. gr. was 7·304. Comparing this with the figures hereinbefore quoted, the tenacity appears so much higher than anything obtained here, that further inquiry would seem to be necessary before such a result ought to be fully received.

121. In 1856 the authorities of the Royal Gun Factory at Woolwich Arsenal (stimulated by the American investigation just named) initiated an elaborate and extensive series of experiments on the strength of various British cast irons with a view to their use for ordnance.

They obtained a testing machine similar to the American one, and arranged it for testing specimens for tensile, compressive, transverse, and torsional strength; and they also undertook the chemical analysis of the samples produced. The results were published in a Blue Book in 1858.

They collected fifty-three samples of various descriptions

of pig iron, prepared for foundry purposes by eighteen different British makers, and simply cast the test specimens from them; these specimens being therefore mostly in the condition of *second melting.** No trials were made of the effects of different meltings, or of any mixtures of different kinds of iron.

The tensile strength was tried on short specimens 1·3 inch diameter, which were pulled asunder in the testing machine.

Eight hundred and fifty specimens were thus tried, and gave the following results:—

	Lbs.		Tons.
Maximum	34,279	=	15·3
Minimum	9,417	=	4·2
The mean of the whole gave	23,257	=	10·4

The Woolwich experimenters made a trial to ascertain the effect of casting under the pressure of a high column of the fluid metal. A bar was cast vertically 26 feet long and 7 inches diameter, and specimens were tested from the top, the middle, and the bottom respectively.

The result showed an increase of specific gravity in the lower portion, but the tensile strength was not increased. In fact, the top specimen was rather the strongest of the three.

They found, moreover, that bars cast *horizontally* were generally stronger, for all strains, than those cast vertically; and that *quick cooling* was also generally favourable to the strength.

I have mentioned that in the Woolwich experiments no attempt was made to ascertain the effect of mixtures of different irons, or the results of different treatment of the *same* iron in the processes of melting. This omission detracts

* Some of the pig supplied was, however, itself second melting, which would make the castings the *third.*

much from the practical utility of the investigation; for it is evidently the duty of every iron-founder to do the best he can with the materials he can obtain; and nobody who knows anything of his business would practically make castings in the way represented by these samples.

The omission is explained in the Report in this way:—"There has been (the reporter says) in the present instance no intention of ascertaining any data relative to the most suitable mixtures of various brands of iron, nor of making experiments as to the treatment of any particular iron with reference to improving its quality; but simply to ascertain that quality as *purchasable in the market*, or when specially supplied as suitable for the particular purpose."

This remark, however, betrays a far greater and more important error than the former; for, instead of obtaining irons *bonâ fide* "purchasable in the market," the promoters of these experiments took the singular step of advertising a complete notice of what they were going to do, and inviting ironmasters to send in samples of their iron for testing!

Now, I must say that, from a very large experience of dealings with the iron trade, I believe it extremely unlikely that the samples sent in by ironmasters, for the express purpose of testing, would correspond with the iron actually sold in the market. And, singularly enough, the Report itself confirms this view; for it appears that, relying on the results obtained with certain of these samples, the authorities ordered large supplies; and it was only *then* that they found out what was really the iron "purchasable in the market." They say:—

"Certain supplies ordered on the results hereafter given, have, on examination, given results *differing much*, both chemically and mechanically, showing superiority in some cases and *inferiority of a very marked character in others.*"

This might naturally have been anticipated; anybody acquainted with the trade would have recommended the experimenters, if they wished to test the market commodity, to go to the market to procure it.

I do not depreciate the value of these experiments; treated generally, they constitute a considerable addition to our knowledge; but if you turn to them to ascertain the value of any particular iron professed to be experimented upon, you must recollect, in the first place, that you have no assurance whatever that the iron really was the kind it professed to be; and secondly, that if it *were* so, different foundry manipulation would probably give different results from what these experiments show.

Strength to Resist Crushing.

122. The strength of cast iron to resist crushing was better understood at an early period than the tensile strength.

Mr. George Rennie communicated to the Transactions of the Royal Society, in 1818, some experiments he made, which gave amounts varying from about 33 to 90 tons per square inch for the crushing force; but the pieces were very small cubes, and the results were uncertain; as it must have been very difficult in these small sizes to tell the exact point of giving way.

Tredgold adds nothing to these data, but he adopts 42 tons as the mean ultimate compressive strength.

123. Mr. Eaton Hodgkinson, in the Report of the Sixth Volume of the British Association Transactions, gives the results of experiments on crushing cast iron, made by him. The specimens were cylinders of from $\frac{1}{4}$ inch to about $\frac{2}{3}$ inch diameter, and rectangular and triangular prisms; the heights varying from $1\frac{1}{2}$ to 3 times the lateral dimension. They were

made of different descriptions of cast iron; apparently all second melting.

The highest result obtained was	..	64·92	tons per square inch.	
The lowest " "	..	36·5	"	"
The mean of 13 experiments ..	..	48	"	"

The crushing took place (as it does in hard crystalline bodies generally) by a wedge sliding off at a certain angle with the base, which angle was generally found constant in the same material.

Mr. Hodgkinson subsequently made a series of experiments on the crushing strength of eighty-one specimens of seventeen different kinds of cast iron, for the Iron Structure Commission of 1849. The specimens were small cylinders of about $\frac{3}{4}$ inch diameter, the height being in some $\frac{3}{4}$ inch and in others $1\frac{1}{2}$ inch.

The highest specimen tried, crushed with	53·8	tons per square inch.	
The lowest " "	24·7	"	"
The mean of all gave	38·5	"	"

A series of experiments were also made at the same time with specimens of different sizes, forms, and proportions, all cut out of the same iron, in order to see if these differences would have any influence on the result; but the strength obtained did not seem to vary more than might have been expected, and appeared always clearly proportional to the area.

The specimens were found to shorten considerably in length, under the pressure, before they ultimately gave way, but the degree of this effect varied considerably, as might be expected, in different kinds of iron.

The ultimate shortening was generally from $\frac{1}{20}$ to $\frac{1}{10}$ of the length.

Some valuable experiments on the strength of cast iron to

resist crushing were also tried by the American experimenters before alluded to.

Their specimens were a little more than ½ inch diameter, and about 1¼ inch long.

A simple iron No. 1 gave—

	Lbs.	Tons.
2nd melting	99,770	44·5
3rd "	139,540	62·5

A mixture of Nos. 1, 2, and 3 gave—

2nd melting	154,576	69·4
3rd "	167,030	74·6

The highest tried was—

	174,120	78

The lowest—

2nd melting	84,529	37·7

It will be noticed that the results obtained in all these cases are very high compared with those obtained from British iron. I am not aware that any satisfactory explanation of the difference has been given. It would be very desirable to have the same irons tried in this country.

The experiments on crushing cast iron at the Woolwich Gun Factory in 1866 were made with small cylinders, 0·6 inch diameter and 1·3 inch high. Two hundred and seventy-three were tried. The whole of the iron was second melting from simple unmixed pig.

	Lbs.	Tons.
The maximum gave	140,056 =	62½
The minimum "	44,563 =	19·8
The mean "	91,061 =	40·6

124. From a comparison of the *tensile* with the *compressive* strength of cast iron, as obtained in the various experiments above referred to, it will appear that the power of this

material to resist crushing is about five or six times greater than to resist tension.

In order to obtain a direct comparison, Mr. Hodgkinson tried, for tension *and* for compression, samples cut out of the *same irons*, taking seventeen varieties of the material.

The highest ratio he obtained was ..	6·7	to	1
The lowest " "	4·5	"	1
The mean of all	5·66	"	1

Transverse Strength.

125. The third kind of strength of cast iron, strength to resist rupture by *transverse* strain, was the first ever tried, being at once the simplest and the easiest to ascertain, and the most directly bearing on the use to which the material was earliest applied, namely, the formation of *beams*.

You will recollect how I have proposed to define the transverse strength, *i.e.* having a bar or beam of rectangular section whose

Length between supports in inches	=	l
Breadth " "	=	b
Depth " "	=	d

Thus, breaking weight hung on the middle in tons $= A\dfrac{b\,d^2}{l}$,

the coefficient A representing the *transverse strength* of the material.

126. Tredgold mentions several previous experiments of this kind, and adds some of his own. But they are entirely superseded by a large series of experiments undertaken by Mr. Fairbairn and Mr. Hodgkinson, on the transverse strength of a very large number of different kinds of iron, the results of which may be fonnd in Mr. Hodgkinson's supplement to the fourth edition of Tredgold's work.

The bars tried were all run second melting from the several pig irons, simple and unmixed; and all made from the same pattern. They were each 1 inch square, and 5 feet long; they were placed on supports 4 ft. 6 in. apart, and weighted in the middle till they broke.

About two hundred and seventy bars were tried, made of iron from fifty-nine different works, in England, Scotland and Wales, both hot and cold blast make. The resulting values of A were:—

Maximum	about	14
Minimum	,,	8·6
Mean of all	,,	10·9

Some experiments on the transverse strength are also recorded in the American Reports already mentioned.

The bars were 20 inches between supports, and about 2 inches square, the breaking weight being hung in the middle.

A certain sample iron, when tested in the pig, gave

1st melting	A = 9·5
When re-melted	10·8
When melted a third time ..	13
,, a fourth time ...	16·8

Another sample, being made from a mixture of three different kinds of pig, gave—

2nd melting	15·7
3rd ,, ...	16

The highest tenacity obtained was represented by the coefficient 17·8. Hence the mixing and the re-melting of iron have the same beneficial influence on the transverse strength as might be expected by analogy from the direct tenacity.

The transverse experiments at the Woolwich Arsenal were tried with bars about 2 inches square, and 20 inches between the bearings, and loaded in the middle till they gave way.

Five hundred and sixty-four specimens were thus tried, and they gave the constant of transverse strength:—

Maximum	= 20
Minimum	= 4·6
Mean	= 12·6

X 127. A valuable series of experiments was undertaken in 1846 and 1847, by Mr. Robert Stephenson, to determine the transverse strength of cast iron, as depending on the *mixtures of the material* from which the castings were made. These were tried with an immediate practical view, namely, to settle the mixtures of iron for casting the large arched girders of the High Level Bridge, then about to be erected at Newcastle-on-Tyne. The account of the experiments was furnished by Mr. Stephenson himself, for publication in the Report of the Iron Structure Commission.

Bars were made:—

1. From nine different kinds of hot-blast iron, being cast directly from the simple melted pig.

2. From five different kinds of cold-blast pig, in the same way.

3. From a considerable number of different *mixtures*, partly of different kinds of pig, and partly of those mixed with scrap; a practice very common in foundries, and which, judiciously done, is attended rather with benefit than disadvantage.

The bars were all 1 inch square, placed on bearings 3 feet apart, and weighted in the middle till they broke.

The highest weight borne was 1072 lbs. by one of the mixtures, the lowest 686, by one of the samples of hot-blast pig. These gave the transverse coefficient 17·2 and 11·0 respectively.

But the principal value of the experiments was in determining the general effect of mixing; and Mr. Stephenson summed up the results as follows:—

1. He found that, although in the specimens tried the

average of the hot-blast iron was not much inferior to the cold, yet that the latter was the more *certain* and *regular*.

2. That mixtures of cold-blast iron were more uniform in strength than those of hot blast.

3. But that mixtures of hot and cold blast together gave a better result than either separately. He also found

4. That simple samples did not run so *solid* as mixtures.

5. That simple samples ran sometimes too hard, sometimes too soft, for practical purposes.

The castings for the bridge were made of a mixture of five different kinds of hot and cold blast, and a certain proportion of selected foundry scrap.

128. I have mentioned, in speaking of cast iron generally, that when it is cast in large masses, it crystallizes differently in different parts of the mass, the external portions (which cool first) being stronger, closer, and harder; while the internal portions are coarser-grained, softer, and weaker, and often spongy and unsound.

Hence small castings will be stronger than large ones cast of the same iron, as having more external surface in proportion to their mass.

Mr. Hodgkinson tried some experiments directly with this view, for the Iron Structure Commission, on bars of the same iron, 1-inch, 2-inch, and 3-inch square respectively.

It was found that the largest bar was, in regard to material, the weakest of the three. The 2-inch bar exceeded it in strength by about 3 or 4 per cent., and the 1-inch by as much as 30 per cent.

Captain James, R.E., in some other experiments for the same Commission, confirmed Mr. Hodgkinson's results; he found that 2-inch square bars were only $\frac{2}{3}$ of the strength computed from 1-inch bars, and bars of 3 inches only $\frac{3}{5}$ the strength.

He also put the cause of this discrepancy directly to the

test by cutting sample bars out of the middle of large castings, and trying them in comparison with bars of the same size and from the same metal, but *cast* smaller.

He found that $\frac{3}{4}$-inch bars cut out of the centre of masses 2 and 3 inches square, were little more than half the strength of bars of the same metal cast 1 inch square.

It is therefore an inference from this, that those coefficients for strength which have been deduced from small bars must be considerably reduced when applied to large masses.

And further, that when (as is often the custom) sample bars are run at the same time with certain castings to test their strength, it must be borne in mind that these bars will not give correct comparisons, unless they are of at least the same size as the thickest portions of the casting exposed to strain.

129. There is an exceedingly simple rough datum for the transverse strength of cast iron, which is well worth committing to memory. It is

That a bar 1 *inch square and* 1 *foot long will break with a load of about* 1 *ton* hung on the middle.

This is equivalent to about an *average* strength, the value of A here being = 12.

Torsional Strength.

130. The last kind of strength of cast iron we have to consider is that to resist *rupture by torsion.*

This has not been so well investigated as the others, but we have still some good data upon it.

We may confine ourselves to the form usually tried, namely, a bar of a *circular section* fixed at one end and twisted at the other.

I have already explained that if d = diameter of bar in inches, M = moment of twisting force which will break the bar (in tons × inches), then $M = A\,d^3$, the constant A representing the strength of the material.

Tredgold reports several experiments on cast-iron shafts, from 2 to 4¼ inches diameter, which I find give A,

Maximum	=	2·56
Minimum	=	2·00
Mean	=	2·34

Mr. Hodgkinson, by inference from some experiments by Mr. Rennie, Messrs. Bramah, and another experimenter, gives A as follows:—

Maximum	=	3·68
Minimum	=	2·13
Mean	=	2·85

The American experimenters took circular bars about 2 inches diameter, and 15 inches long in the strained part, and tested them by torsion in the machine previously referred to.

The values of A obtained were:—

For a certain simple iron, 2nd melting	=	2·75
Ditto, 3rd melting	=	3·93
For a mixture of two different kinds of iron, 2nd melting	=	3·5
Ditto, 3rd melting	=	4·7
The highest obtained was	=	4·7
The lowest, 2nd melting, obtained was	=	2·5

The same experimenters also tried the torsional strength of bars of different sizes and shapes, such as squares and hollow cylinders. The results will be found in the Reports, but it is unnecessary to give them in detail here.

The Woolwich Gun Factory experiments on the torsional strength of cast iron were made with cylinders 8 inches long in the twisted part, and 1·8 inch diameter.

Two hundred and seventy-six specimens were tried, and gave the constant of torsional strength :—

	Lbs.	Tons.
Maximum	9773 ..	4·4
Minimum	3705 ..	1·65
Mean	6056 ..	2·7

M. Morin (Art. 599) gives an account of some experiments on cast-iron shafts 1½ mètre long and 10 centimètres (3·94 inches) diameter. The lever was 2 mètres (78·3 inches) long; and the breaking weights applied varied from 1600 to 2250 kilogrammes, giving the constant of torsional strength 2·05 to 2·90.

131. Having now gone through the strength of cast iron, as exhibited in the several modes in which it may be tried, I must call your earnest attention to a remark which applies to all alike, and which ought to be always present in the engineer's mind when he applies iron to practical uses.

The figures I have given you are the *ultimate* strengths, *i. e.* they represent the points at which the iron will *break.*

Now, of course, common sense would tell you that in proportioning the strength of an iron structure, the weight or strain allowed to come upon it must always be much less than is sufficient to break it; but *how much less* it ought to be is a question that deserves inquiry; or, as Mr. Rankine expresses it, what should be the *working* strength for a given ultimate strength.

It is a question which has occupied the attention of engineers ever since iron has been used, and it is of considerable importance; for while on the one hand it is necessary to make the structure *perfectly safe,* on the other it is desirable not to waste material in making it stronger than safety requires.

It might, perhaps, at first, be supposed that if we can

determine the breaking weight accurately, we should be safe as long as we keep within it; thus, if we know a bar will not break with less than 10 tons, it might appear that we may safely put on 8 or 9.

But this supposition overlooks an important fact, that is, that the material will be much *damaged* long before the strain approaches the breaking point; and it is a principle which engineers have always thought it prudent to act on, that a material should never be strained to such an extent as to damage its texture.

In speaking of elasticity and flexibility, I have told you that when the deflection or disturbance of form by strain exceeds the limit of the natural elasticity of the material, it refuses to return to its former position, or takes what is called a *permanent set.* At this point, therefore, the material becomes, if not damaged, at least *distorted.* And (with, I think, good reason) practical men appear to have decided that this limit, *i. e.* the limit of the elastic power of the material, ought to form the limit of the practical strain to which it should be exposed.

In regard to cast iron, theoretically speaking, in consequence of the imperfect elasticity, the permanent set begins at a very early point; but, *practically*, it may be considered insignificant until the strain arrives at about *one-third* the breaking point, when it becomes practically sensible.

For this reason, the general rule practically adopted by engineers for cast iron is, to limit the strain which can come upon it from a permanent stationary load, to one-third or one-fourth that which would break it.

And in the case of a *moving load* (such as for trains passing over a railway bridge), which gives shocks and concussions, *one-sixth* is the limit considered safe.

One-third and one-sixth respectively in these two cases are the limits sanctioned by the Board of Trade.

132. There are one or two other general remarks to be made on the strength of cast iron.

In the first place, it has been well established that the strength of this material, when moderately loaded, is not impaired by a long continuance of the strains upon it. Mr. Hodgkinson found that cast-iron beams sustained their load for many years without appearing weaker at the end than at the beginning of the period.

No doubt there are cases where cast-iron beams have given way after continued use; but we are bound to suppose them, either through misproportion or unseen defects, to have been always under undue strain.

133. Secondly, it has also been established by the investigation of the Iron Structure Commission, that, provided the strain applied be within the practical limit of the elasticity (or say one-third of the breaking weight), the iron is not weakened by the constant *repetition* of the strain, even to many thousands of times.

But when the strain is greater than this, the metal becomes weakened, and will ultimately give way.

134. Then, thirdly, it has also been proved that *differences of temperature*, within a moderate range, have little or no influence on the strength of cast iron. Trials have been made on bars under various degrees of heat, and it has been found that the strength is not materially altered within a range of from *freezing* to 600 *Fahr.*, or nearly that of melting lead.

Stiffness and Elasticity.

135. The next property of cast iron that deserves mention is its *stiffness* to resist distortion of form. This property, as I have already explained to you (Arts. 92, 93), is usually measured by a constant called the *modulus of elasticity*, which

assumes that, up to a certain limit (beyond which the strain is not supposed to be carried), the elasticity of the material remains perfect.

The tests of this perfect elasticity, you will recollect, are that, in the first place, it shall return perfectly to its original form and position as soon as the distorting force is removed; and, secondly, that the quantity of extension or compression under a given strain shall be equal to each other, and proportional to the force applied—according to Dr. Hooke's law, *ut tensio sic vis.*

136. Now it was long supposed that cast iron retained its perfect elasticity under considerable strain. Tredgold inferred, from the experiments he could collect, that if cast iron was loaded up to about one-third of its breaking weight, its elasticity was not impaired, but that it would return to its original form.

At a later date, however, Mr. Eaton Hodgkinson discovered, by more accurate investigation, that this opinion was not strictly correct, but that the elasticity of cast iron was impaired much earlier than had been supposed. He also arrived at a rule which (though empirical in its constitution) sufficiently well expressed the departure of the material from Dr. Hooke's law. Let

l = length of a bar in inches,
λ = extension or compression produced therein by a certain force,
$\frac{\lambda}{l}$ being then the *proportionate* compression or extension of the bar.

Then on the principle of *ut tensio sic vis*, the force necessary to produce this alteration would be

$$= \text{Const.} \times A \frac{\lambda}{l}.$$

But Mr. Hodgkinson found that the *real* force necessary

(which we will call f) followed the more complicated expression

$$f = A\frac{\lambda}{l} - B\left(\frac{\lambda}{l}\right)^2,$$

where A and B are constants to be determined by experiments.

This law was published by Mr. Hodgkinson in 1843.

In 1849 the Royal Commission on Iron Structures instructed Mr. Hodgkinson to try some further experiments in order to determine these constants.

The experiments were made by taking bars of about 1 inch square, and 50 feet long, loading them with varying weights, so as either to compress or extend them, and then very carefully measuring the compression or extension produced.

They were made on four different kinds of the metal; and the mean of the whole gave the following, for a bar 1 inch square, the force being in tons:—

$$\textit{Extension.} \quad f = 6220\frac{\lambda}{l} - 1{,}297{,}960\left(\frac{\lambda}{l}\right)^2.$$

$$\textit{Compression.} \quad f = 5773\frac{\lambda}{l} - 233{,}472\left(\frac{\lambda}{l}\right)^2.$$

The four different kinds of iron on which these rules were founded gave results not much differing from each other; but I think it probable, from analogy with other knowledge of cast iron, that, had a greater variety of specimens been tried, we should have had wider discrepancies, and that the stiffness and elasticity of different kinds of iron would have probably been found to vary as widely as we have found the strength to do.

However, we may take the above results as probably the most accurate data we possess on the elasticity of cast iron.

Mr. Hodgkinson also deduced rules for finding the *per-*

manent set which would result from a given extension of cast iron. Let

$$e = \text{extension in inches,}$$

then

$$\text{Permanent set} = 0 \cdot 0193\, e + 0 \cdot 64\, e^2.$$

He also tried whether the results he had obtained as to the extensibility of long bars strained in the direction of their length, would also be borne out in bars weighted transversely, these bars being made very flexible, to show the deflections and sets more clearly.

He found the same rule apply, as the deflections might be determined by an equation of the form:—

$$\text{Weight on middle} = \text{A}\, d + \text{B}\, d^2,$$

the constants A and B depending of course on the dimensions of the bar, as well as to some extent on the character of the iron.

He also found the permanent set $= \dfrac{d^2}{31 \cdot 35}$ nearly.

137. It is clear, from the above results, that, owing to the imperfect elasticity of cast iron, we cannot deduce a *modulus of elasticity* which shall answer with perfect exactness, as this assumes that the material will extend or compress equally for equal increments of force, and moreover that the amounts of extension and compression will be equal for the same force applied.

But it is very useful to have a datum of the kind for cast iron, even though its results may only be approximate; and if we examine the results of experiment, we shall find that for small strains they are still so near uniformity, that we may determine this datum with tolerable accuracy.

If we calculate out the above equations for moderate strains, we shall find that for a 1-inch bar—

The first ton will extend or compress it in round numbers about $\frac{1}{6000}$ of its length.

Or, the mean of the first 5 tons will give for each ton about $\frac{1}{5000}$ of its length.

These data therefore give the modulus of elasticity a quantity varying from 5000 to 6000 tons.

Other deductions, by different experimenters, have given results varying from 4000 to 8000 tons, a variation which is to be expected in different qualities of iron.

We may probably take a value of 5500 as expressing a fair practical mean for the modulus of elasticity of cast iron.

138. When we come to compare the flexibility of cast iron with that of wrought, and also compare their respective strengths to resist crushing, we shall find the remarkable fact, that although cast iron will *yield* nearly *twice as much* (to a given compressing strain) as wrought iron will, yet it will withstand *three times the strain* without crushing; a curious disproportion, in the two cases, between the resistance to change of form and the resistance to rupture.

Ductility.

139. The next mechanical property on our list is *ductility*.

It may, at first sight, seem out of the question to speak of the ductility of cast iron, this material being generally considered notorious for the absence of such a quality. Still, however, as the property *does exist* in cast iron in an amount which is appreciable, though very minute, it is right to give what data there are upon it.

It is well known that cast iron will, if the limit of elasticity is exceeded, become somewhat altered in form before it breaks, and this is sufficient to constitute a certain amount of ductility.

140. I have defined the measure of ductility to be the proportion which a bar will elongate, under tensile strain, before it breaks.

Mr. Hodgkinson's careful and delicate experiments on very long bars of cast iron have shown ultimate elongations varying from $\frac{1}{500}$ to about $\frac{1}{800}$ of their length.

The mean of all his experiments showed a value of about $\frac{1}{600}$.

These figures will therefore express the ductility of cast iron.

141. With the aid of this we may further find the value of what I have called Mallet's coefficient, *i.e.* the amount of *mechanical work* done in the rupture, by tension, of a bar 1 inch square and 1 foot long, and which, you will recollect, is simply

$\frac{1}{2}$ breaking weight in lbs. × ultimate elongation in feet.

The lowest obtained in Mr. Hodgkinson's experiments was—

Breaking weight, 13,089 lbs. Elongation = ·0012.

Therefore the

Work was = 7·85.

The highest was—

Breaking weight, 16,890 lbs. Elongation ·00195.

Work = 16·5.

The mean obtained in these experiments was—

Breaking weight, 7 tons. Elongation $\frac{1}{600}$.

Work = 13·0.

Hardness.

142. I have mentioned the American mode of estimating the comparative hardness of different kinds of cast iron,

namely, by indenting it with a pyramidical pointed tool under a heavy pressure.

It was found that when the softest kind of metal ever used for cannon was tried, the tool, under a pressure of 10,000 lbs. would enter a little less than the maximum size of the pyramid, *i. e.* $3\frac{1}{3}$ cubic tenths; it was therefore assumed that a metal in which the whole pyramid would enter might, for want of a better standard, be made the unit of comparison, the hardness being estimated inversely by the cubic indentation of the tool. I shall in my statements call this least hardness = 1 (although the experimenters gave it a different value, rather more complicated).

One of the softest metals actually tried was bronze; and this gave, according to the above standard, a hardness = 1·36.

But there was a variety of very soft No. 1 pig iron which gave exactly a similar result.

The hardest cast iron tried gave	10·1
A certain No. 1 pig, 1st melting, gave	2·55
" " 2 " "	4·15
" " 3 " "	6·4

No. 1 iron gave

Pig	1st melting	2·55
Castings,	2nd "	3·6
"	3rd "	5·9
"	4th "	8·8

Mixtures of different kinds of iron gave moderate hardness, which was always increased by re-melting.

The hardness almost always increased with the specific gravity.

Some *wrought* iron tried at the same time gave a hardness, = 3·32.

SPECIFIC GRAVITY.

143. The specific gravity of iron varies from about 6·85 to 7·35.

It depends not only on the natural quality of the material, but also on its mode of casting, as it has been found that the lower portions of castings, lying under a heavy hydrostatic pressure of fluid metal, prove more dense, when cool, than those nearer the top.

The Woolwich experimenters showed this; for by taking portions of a long bar cast vertically, they found

Top	7·217
13 feet lower	7·263
26 feet (bottom)	7·324

Mr. Mallet also found the same thing in one specimen—

Surface	7·048
14 feet down	7·14

In others it was less, but always increasing with the depth in the mould.

The specific gravity of cast iron may be taken at a mean of about 7·1.

144. It is useful to deduce a simple practical rule for *estimating the weight* of articles in cast iron.

From the mean specific gravity above given, 1 cubic foot will weigh 7100 ounces, or 443 lbs. avoirdupois, or 1 cubic inch will weigh a little over a quarter of a pound (0·256); therefore, to ascertain the weight a casting will be, divide the number of cubic inches by 4, and that will give the probable weight in pounds very nearly.

145. It is not unreasonable to conjecture that the different properties of iron may have some kind of analogy between

themselves, *i. e.* that iron which excels or falls short in some qualities, may also do the same in others.

The Americans have prepared a table from their experiments, in which they show that the specific gravity of cast iron forms an index to its value in all kinds of strength and in hardness, *i. e.* that the different kinds of strength, the specific gravity and the hardness, increase with each other.

The only exception seems to be that the very heaviest and very hardest iron falls off somewhat in tenacity, becoming in all probability weaker from extreme brittleness.

General Remarks on Cast Iron.

146. I have now only a few remarks, of a more general nature, to make on cast iron.

The greatest advantage the material possesses is the *facility with which*, by fusion, *it can be manufactured into any given shape.*

I need scarcely point out what a benefit this is in furthering the production of the immensely varied and complicated shapes which ironwork is obliged to assume, and which would be so extremely difficult to obtain in any other way. The construction of machinery, for example, would be almost forbidden, if the multitudinous and varied forms of which many of its parts consist could not be made in cast iron.

It is true that where necessity compels *wrought iron* to be used, great skill has been exercised in adapting it to complicated shapes; but this adaptation is always very expensive in comparison with the more simple mode of casting them.

In all cases, therefore, where cast iron is sufficient for the purpose, the facility and cheapness of its manufacture will determine its adoption.

147. But we must not conceal the disadvantages peculiar to cast iron, of which there are two, that for many purposes either restrict its use or forbid it altogether.

The first is its *uncertainty* or *untrustworthiness.* Take all the care we will in making a casting, we cannot ensure its being what we expect it to be.

There are several causes which may make a casting unsound. The air may not get freely away from the mould; or the moisture in the sand may blow; or pieces of sand may become detached and run among the iron; or the metal may not run well together in all parts, thus forming unjoined portions, or "*cold shuts*" as they are called; or it may shrink and contract internally, and leave holes or spongy places.

Any of these causes will produce *unsound* castings, and unfortunately the defects may either be out of sight, or may be wilfully concealed by the workmen (often done, I am sorry to say, so cleverly as to deceive the most practised eye), and in these cases any trust based on the calculated strength will be fallacious.

Hence, the chance of hidden defects or faulty places in cast iron must always be considered as a contingency inevitably connected with its use; and must be provided for by a margin or excess of strength.

And experience shows that the rule I have before mentioned, of keeping down the strain to about one-third or one-fourth the breaking weight, is usually (with care in the casting) considered sufficient to meet this contingency.

But further, although no positive unsoundness may be developed, yet it may often happen that, from peculiarities in the shape of the casting, the *contraction in cooling* may proceed so irregularly as to put certain portions of the casting into a state of abnormal, and sometimes dangerous, strain. Certain parts, for example, of small dimensions will consoli-

date quickly, while the larger masses retain their fluidity; and when these latter also begin to contract, the former cannot give way along with them, and thus portions are thrown into high tension.

It is well known that castings will often, from this cause, fly to pieces when cold on receiving slight jars. A familiar example is a cast-iron wheel, of which the spokes and rim are thin, while the nave is a large mass; if no precaution is taken in casting the spokes will be highly strained, and under the jar of use will be sure to fly.

Founders are well aware of this circumstance, and usually take precautions in some measure against it. But still it must be borne in mind as one of the defects to which cast iron is liable.

148. Another important disadvantage of cast iron for constructive purposes, is its *brittleness*, which specially unfits it for use in all cases where it is subject to concussions or vibrations, or heavy impact; or at least renders it necessary, in such cases, to provide considerable excess of strength.

149. To obviate the brittleness of cast iron, and at the same time to take advantage of its extreme facility of manufacture, an invention has lately been brought into use, for small castings, which has been of great utility—*viz.* the manufacture of what is called *malleable cast iron.*

The castings are made from very soft and pure *charcoal pig* iron, and are afterwards kept for some days, at a bright red heat, imbedded in powdered red hematite ore. The action of this is very curious, being just the reverse of the operation of carburizing or making steel, called cementation—this latter infuses carbon into iron, but the action of the hematite is to *extract* the carbon from the cast iron, and thus convert it into an impure wrought iron. In some analyses of the

metal by Dr. Miller, before and after treatment, the operation was found to have reduced the carbon from 2·80 to 0·88 per cent., as well as to have sensibly increased the specific gravity, and diminished the quantities of silicon and sulphur, thus otherwise improving the metal.

Articles of cast iron so treated become to a certain extent malleable; their brittleness is gone, and they may be thrown about, or even bent and hammered without breaking.

The malleable cast iron process is largely used for small Birmingham manufactures, but is yet, from the trouble and expense attending it, hardly adapted for castings in general.

150. We may say that cast-iron, as ordinarily known, is practically wanting in the qualities of malleability and ductility which are so inestimable in *wrought iron*, as enabling it not only to bear concussions and impacts, but also to undergo forging and fashioning operations in the workshop.

It is curious to observe the strikingly different effect of the combination of carbon with iron, as manifested in steel and in cast iron. The small proportion in steel has the effect of improving the iron in almost every quality. It increases its strength, its stiffness, its elasticity, its hardness, its ductility, its malleability, and gives it in addition many new and curious properties of the highest value.

But increase the dose of carbon a little more, so as to produce cast iron, and see what a change takes place: its tenacity, stiffness, elasticity, hardness, all sink again even below their original amounts; and the ductility and malleability have vanished altogether.

When cast iron has to be used in a structure, it must be cast as nearly as possible in the form intended, the only operations it can undergo in the factory being such as turning, boring, or planing, to give accuracy to the surfaces, and drilling, to form any necessary holes. When several

pieces have to be fastened together, this is done by screw-bolts and nuts, in a way with which everybody is familiar.

151. Cast iron is not so liable to rust as wrought iron; but when it is long exposed to the action of sea water a curious change takes place, the solid iron becoming converted either wholly or partially into a soft grey porous mass, something of a graphitic character, which heats and falls to pieces on exposure to the air.* The chemical nature of this phenomenon is not well explained, but it is important for the engineer to know of the liability of the metal to such a change.

152. I may add a word or two as to the *price* of cast iron. Pig iron is sold for about 2*l.* 10*s.* to 5*l.* per ton, dependent on the quality and the state of the market.

Castings vary much in price, according to their nature, and the places where they are made.

Large castings, or even small ones made in large numbers, such as railway chairs, cast in large manufactories favourably located, may be had from, say 4*l.* to 8*l.* per ton; more complicated ones, requiring more care, and made in smaller foundries, will range from the latter price up to double, according to circumstances.

153 The following Table exhibits in a condensed form the chief results in regard to cast iron given in the foregoing pages.

* Percy, page 146.

Mechanical Properties of Cast Iron.

	Maximum.	Minimum.	Mean.
Tenacity.	Tons per square inch.		
Hodgkinson	11·5	4·9	7·1
American	20·5	..	..
Woolwich	15·3	4·2	10·4
Compressive Strength.			
Hodgkinson	65	25	40
American	78	38	..
Woolwich	62·5	20	41
Transverse Strength.	Coefficients.		
Hodgkinson	14	8·6	10·9
American	17·8	9·5	..
Woolwich	20	4·6	12·6
Stephenson	17·2	11	..
Mnemonic rule	..	..	12
Torsional Strength.	Coefficients.		
Tredgold	2·56	2	2·34
Hodgkinson	3·68	2·13	2·85
American	4·7	2·5	..
Woolwich	4·4	1·65	2·7
Stiffness.	Tons for 1 inch square.		
Modulus of elasticity	8000	4000	5500
Ductility.	Per unit of length.		
Ultimate elongation	0·002	0·00125	0·00166
Toughness.	Of bar 1 inch square, 1 foot long.		
Work done in rupture	16·50	7·85	13
Hardness.	Comparative.		
Cubic indentation	10·10	1·36	..
Specific Gravity	7·35	6·85	7·1

SUMMARY AS REGARDS CAST IRON.

154. Let us now briefly sum up the principal points of the knowledge we possess guiding us to the structural use and application of cast iron.

a. The great recommendation of the material is, the facility and cheapness with which it can be fashioned into any form, however complicated, that may be required.

b. We find that the *strength* of cast iron is variable, extending over a very wide range; this strength depending not only on the original material used, but on its manipulation and treatment in founding. We find also:—

c. That it is very strong to resist *compressive* or *crushing strains*, for which duty (as we shall see hereafter) it is much better suited than wrought iron.

It ought, therefore, generally to be preferred if possible for parts of iron structures where strains of this nature occur, such as bearings, short columns and struts, arches, &c., &c.

d. But that it is *weak* to resist *tensile* strains, for which (as we shall see hereafter) wrought iron is very much preferable.

Therefore cast iron should be used with great caution for those parts of a structure subject to tensile stress.

e. That the elasticity of cast iron is imperfect, even under light strains; but that as an approximate practical datum, the modulus of elastic stiffness may be taken at about 5000.

f. That the hardness of cast iron is very different in different specimens, varying from almost the hardness of steel to the softness of bronze; and that these variations depend (like the strength) both on the original material and on the manipulation.

g. That, generally speaking, the strength and the hardness increase with the specific gravity.

h. That castings are always uncertain in their quality, and liable to hidden defects and flaws, which may much weaken them, and to allow for which an ample margin of extra strength should always be provided.

i. That *large* castings are not so strong (in proportion to their dimensions) as smaller ones; the internal portions of large masses being weaker than the external.

k. That cast iron is brittle and wanting in toughness and ductility, which unfits it to bear concussions, vibrations, or heavy impact, unless it is given a great excess of strength.

CHAPTER V.

MALLEABLE IRON.

155. I now come to speak of a variety of iron which is of a higher character than that already treated of—namely, *malleable iron*, or, as it is more generally termed when manufactured, *wrought iron*.

It is of a higher character, because it is so much *purer*. Cast iron, as you know, is a compound of iron with a large dose of carbon and other foreign ingredients; wrought iron is the nearest thing we can practically obtain to the pure unalloyed metal.

The French acknowledge this distinction in their nomenclature, though we do not: they never use the word *fer* for cast iron, always *fonte;* the word "*fer*" being exclusively devoted to malleable iron.

I shall devote this chapter to the *general properties* of wrought iron, and then go on to notice particular kinds of the material.

156. First, as to its *strength*. You will recollect that in treating of cast iron I told you that the strength of the material might be considered as manifested in four different ways—*i. e.* in resisting rupture either by *tension*, *compression*, *transverse loading*, or *torsion*.

Now we cannot fully carry out the parallel with wrought iron, for the reason that in the two latter modes it would

often be difficult (with ordinarily good material) to produce rupture at all, in consequence of the *ductility* of the iron.

If we load a bar of cast iron transversely it will bend, wrought? if of good quality, almost double before it will break; and so no limit of its transverse strength to resist rupture can be obtained. Similarly, if we try to *twist* a good wrought-iron bar, we may almost turn it into a corkscrew before it will snap off.

But in the two first-named points the strength of wrought iron to resist rupture is perfectly amenable to determination.

If, for example, we fasten one end of a wrought-iron bar to the ceiling, and hang a weight to the other end, we shall easily find out what weight will tear it in two, which will thus be its *ultimate tensile strength*, or *tenacity*.

Or if we take a short wrought-iron pillar, and put a heavy weight on the top of it, we shall soon find the point at which the material will fail under the weight, and this will be its ultimate strength to resist *crushing*.

We will therefore consider these two kinds of strength in order.

TENSILE STRENGTH.

157. The strength of wrought iron to resist rupture by tensile stress (or as I have called it more briefly, the *tenacity*) is one of its most valuable properties, and the one which has, perhaps, more than any other, led to its extensive modern use. This quality has, therefore, often commended itself to the attention of engineers, and has been well investigated.

Like every other quality of this wonderful material, the tenacity is *exceedingly variable* in different samples. It depends chiefly on the original quality and manufacture of the material, but I shall have occasion to show hereafter that the size, shape, and treatment of the specimens have also some influence on the strength obtained.

We shall find, for example, that plates, large forgings, small wire, and other special forms have peculiarities in regard to their tenacity which require particular mention.

But in speaking of the *general tenacity* of wrought iron it will be most convenient to confine our attention to the simplest shape in which it appears in the market, and, indeed, in which by far the larger portion of it is made and sold—namely, *wrought-iron bar*.

And we shall denote the ultimate tenacity, as before, by giving the *weight in tons* that will tear asunder, by direct longitudinal tension, a bar of one square inch in sectional area.

158. Early experiments are on record on this subject.

Some by Muschenbröck, in 1762, are quoted, which give the tenacity of

Ordinary iron bars	30	tons per square inch.
Styrian	33½	"
Best Swedish and Russian	37½	"

But the *sizes* of these specimens were only about $\frac{1}{25}$ of a square inch area—*i. e.* they were really large *wire;* and we shall see hereafter that they do not represent the strength of iron *bar*, properly so called.

Rumford is said to have found the tenacity of good iron 24½ tons; of the best, 29½ tons.

Mr. Telford tried several kinds of iron—Welsh, Swedish, and Staffordshire—and found the tenacity vary from 27½ to nearly 32 tons.

Captain Brown, the inventor of the modern suspension bridge, obtained 23 to 26½ tons.

Mr. Lloyd obtained from Staffordshire S C iron from 24 to 29 tons.

Mr. Edwin Clark tried samples of the best scrap rivet iron, the quality being unusually good, and the fracture

beautifully fibrous, and found the tenacity 24 tons per square inch.

The American Board of Ordnance found the tenacity of

	Tons.
Russian iron	28
English rolled	25
Low Moor	25
American hammered	24

I myself had occasion, some years ago, to make some experiments on the tenacity of wrought-iron bars used for bridge building, and found them vary from 19½ to 24 tons.

159. But the latest and most extensive data we have on the strength of malleable iron are from experiments made under the direction of Messrs. Robert Napier and Son, of Glasgow, the operator being Mr. David Kirkaldy, who has published the experiments in full. I have already alluded to these experiments, and, as I shall hereafter frequently have occasion to quote them, I may here say at once what little of introduction they require.

Some few years ago Messrs. Napier, wishing to ascertain the merits of some kinds of steel newly introduced, commissioned Mr. Kirkaldy to experiment on them; but the inquiry appeared likely to lead to interesting results; and, as Messrs. Napier at that time had undertaken the construction of two iron ships of war, the 'Black Prince' and the 'Hector,' they extended the investigation generally to the use of iron for structural purposes, and for ship-building in particular. The experiments were very numerous and comprehensive. They comprised trials of the tenacity, elasticity, and ductility of steel bars, in great variety; of wrought-iron bars, in greater variety still; of steel and iron plates, tested in various directions; of iron straps and angle iron, and of various descriptions of iron manufactured by different processes, as

rolling, hammering, &c., together with experimental investigations on different modes of treatment in the use of iron or steel; on different shapes and sizes of specimens; on the strength of bolts, made in different ways; on welded joints; on the application of sudden strains, and so on.

The experiments, on the whole, were above 1500 in number; and they seem to have been conducted with great care, and considerable knowledge of the subject.

The first precaution was, in itself, a proof of this; for the experimenters, instead of adopting the Woolwich mode of advertising what they were about to do, and inviting the iron-makers to send samples, prepared for the occasion, said nothing about their intentions, but quietly took their specimens from iron *actually purchased in the market*, the makers knowing nothing about the proceeding till it was all over.

It is a somewhat curious comment on both this and the Woolwich plan, that as soon as some of the makers learned what had been done, they were exceeding wroth, and actually attempted (by the threat of legal proceedings) to suppress the publication, under the plea that the specimens had not been procured directly for the purpose!

Several pieces were always tested of each make to obtain an average; and generally several specimens were taken from each plate or each bar.

160. In these experiments, too, an element was noted and reasoned upon, which does not seem previously to have attracted much attention, but which has considerable influence on the application of the results to practical purposes.

This is, the effect of the *ductility* of the iron, in allowing it to *stretch*, and consequently to *contract in area* before breaking.

All wrought-iron bars, if of ordinarily good quality, will stretch under heavy strain, and in thus elongating they

will contract in their transverse dimensions, some of the best and most ductile ones as much as 50 or 60 per cent.; *i.e.* a bar originally 1 inch square will become reduced at the point of fracture to, say $\frac{1}{2}$ inch area, or less.

The way in which this occurs with very ductile iron is somewhat peculiar. At first, the stretching takes place nearly *uniformly over the whole length of the bar;* and this will go on, with the best irons, to the extent, perhaps, of some 15 or 20 per cent.

But when the strain approaches breaking, a more irregular result usually happens; some part of the bar will prove to be weaker than the rest, and at this point the metal will suddenly *draw out,* the cross area will rapidly contract, and the bar will break at this diminished section.

Now, it is a curious question, how ought the tenacity to be denoted? Suppose the bar, originally 1 inch, and reduced at the fracture to $\frac{1}{2}$ inch area, breaks with 15 tons, ought its tenacity to be called 15 or 30 tons per square inch? On the one hand, it is quite true that 15 tons has broken a 1-inch bar; but, on the other hand, it is also true that the metal itself has taken 30 tons per square inch to break it through.

Postponing for the present the question of how the *engineer* should consider this in applying the results, it is quite clear that it is the duty of the *experimenter* to give *both* data; to furnish, in fact, the full details of the experiment, from which the person studying it can draw such inferences as he may desire. For, independently of the tenacity of the iron, the elongation and the contraction of area furnish valuable means of judging of its *ductility*, as I shall hereafter show.

Mr. Kirkaldy has carefully ascertained and given these data, and has calculated the tenacity in both ways. He found that the contraction of fractured area varied from 5 to 30, 40, 50, and in some cases to even 60 or 70 per cent.

161. The wrought-iron bars tried for tenacity were generally about $\frac{3}{4}$ to 1 inch square or round, and were of many different makes,—foreign, Yorkshire, Staffordshire, Scotch, and Welsh.

Estimating the tenacity by the *area of fracture*, the highest tenacity obtained was a certain Swedish iron, that gave the enormous amount of 84 tons.

The lowest was a Scotch iron = 26 tons.

But estimating, as is more customary and more practical, by the *original* area of the bar—

The highest was a single specimen of a Scotch rivet-iron, giving 30·7 tons.

The lowest was also a Scotch iron, a little under 20 tons.

The general mean was about 25 or 26 tons.

X 162. I must, however, revert for a moment to the question, which of these estimates of tenacity is the best guide for the engineer in using the metal? Should he take the tenacity on the *original*, or on the *fractured* area?

Suppose, for example, he had to choose between two irons, one which scarcely stretched at all, and broke with 20 tons to the inch; the other, which reduced one-half, and *then* broke with 30 tons to the inch of reduced area, being *fifteen tons* only on the original size.

Ought the second iron to be called weaker, or stronger than the first?

As a metal, it would be certainly stronger; but, in a practical sense, the weight that *a bar of a certain size* would bear would be less than the other. Thus, therefore, we should get the anomalous result, that the more tenacious and more ductile iron (and probably much the better iron in every point of view) was really the *weaker* when applied in a bar of a certain size, the weakness being due, however, in this case, not to want of tenacity, but to the reduction of area consequent on the ductility.

The practical effect of this reduction in area of fracture was put to the test by trying comparative samples of the *same iron*, some of which were so shaped as not to admit of the metal drawing out or elongating, but to compel it to break at or near the original area. And it was found, naturally enough, that the bar which could not elongate would bear a considerably higher strain *per square inch of original area* than that which could do so.

I am inclined to think that the old-fashioned way of denoting the tenacity by the *original area of the bar* is the simplest and most straightforward, and the least likely to create confusion, and that, therefore, it is the best to adhere to.

But it must always be borne in mind that this datum, if taken alone and unqualified, would make a hard, brittle, inferior iron, seem superior to one very much preferable in almost every respect; and that the engineer, therefore, must be careful not to base his judgment on simple tenacity alone, but must always take account of the other qualities of iron, particularly its ductility. For though a hard and brittle, but tenacious description of iron might suspend, under a steady load, a higher weight than a better and more ductile one (owing to its retaining nearly its full section to the last), yet such an iron would be highly unfit for the great majority of the purposes where wrought iron is used, and where the power of withstanding jerks and sudden blows is necessary, for which only a tough and ductile quality would be proper.

It is worthy of remark that the most ductile qualities of iron have (from their generally superior character) the great advantage of more *uniformity* in their strength than the common and more brittle kinds. Mr. Kirkaldy found that some of the best and most ductile irons only varied in different specimens about 4 to 5 per cent., while the harder and commoner sorts varied 30 or 40 per cent. As an example, the iron which in one specimen showed the highest

tenacity of all (30·7 tons), gave in another specimen almost the lowest (21 tons). This was a hard, unyielding, common iron.

The thing I am most surprised at in these experiments is, that the *minimum* tenacity is so high as 20 tons. It seems strange to me that among all the specimens of bar iron Mr. Kirkaldy tried, he should not have got any weaker; for I know by my own experience, corroborated by the general knowledge of engineers, that bar iron is often met with that will break with considerably under 20 tons; indeed, wrought iron is sometimes seen, particularly in cheap rails, which is great rubbish, not much better than cast iron.

163. Mr. Styffe gives (Tables I. and II.) several experiments on Swedish irons.

Taking the *original area* of the bars, the highest tenacity was about 24 tons; the lowest, about 20 tons; the mean, nearly 22 tons.

The mean breaking weight on the *reduced* area of fracture was 52½ tons, the irons being very ductile.

164. I have generally found it safe to assume that the tenacity of wrought-iron bars (estimated by the original area) will vary from about 15 tons in the worst, to about 30 tons in the best qualities; and, as a practical rule, whenever wrought bar-iron is specified to be used for structural purposes, it should be stipulated to be of such a tenacity as to withstand at least 20 tons per square inch without breaking. This is by no means a severe test for iron bar, and iron which will not stand it ought to be rejected as inferior.

At the same time, as I have before observed, the goodness of the iron is not to be measured by its *tenacity* only; the other qualities good iron ought to possess will be mentioned as we pass on.

STRENGTH OF WROUGHT IRON TO RESIST CRUSHING.

165. The second kind of strength to be considered in malleable iron is that to resist destruction by *compressive force*, or crushing.

This is more difficult to determine with exactness in wrought iron than in cast, owing to the greater ductility of wrought iron, and the different way it behaves under compressive strain.

When a small piece (say, a cube of an inch on each side) of wrought iron is exposed to a gradually-increasing compressive force, it resists for some time any violent change; but as the crushing force increases, the shape and proportions begin to suffer; and at last, if the metal is tolerably ductile, it will begin to ooze gradually away, like a lump of lead in a vice, or a red-hot rivet under the pressure of the riveting machine.

Hence, as Mr. Hodgkinson has pertinently remarked, there is, with tolerably good wrought iron, no such *abrupt change* as to enable an experimenter to define the exact point at which the crushing may be said to occur.

166. Sufficient has, however, been observed to enable us to arrive at some general idea of the resistance of wrought iron to a compressive force; and it may be taken about as follows:—

With a force of about 9 or 10 tons per square inch, the permanent shortening becomes perceptible.

With somewhat more (say about 12 tons) the distortion becomes more marked, the shape and proportions beginning to suffer; and this, therefore, may be considered the limit of the utility of the material in resisting compressive strains.

It still, however, takes more pressure, *viz.* about 16 tons, to cause the metal to give way.

No doubt these results would be found to vary considerably in different specimens of iron; but, for the reason I have stated, we have but few data on the subject, and must therefore be content to take the general results as I have given them.

Stiffness and Elasticity.

167. We have next to consider the behaviour of wrought iron under strains *short* of the breaking force.

Suppose, as before, our 1-inch bar hung up by one end, and a moderate weight hung to the other end; it will stretch a certain amount, dependent on its *stiffness* (or inversely its pliability), while its power to recover itself when the weight is removed is due to its *elasticity*.

In both these respects, wrought iron has the advantage over cast iron.

168. First, as to its *elasticity*. This is *more perfect* than in cast iron, inasmuch as the law *ut tensio sic vis* applies much more truly and extensively.

In some experiments by Mr. Hodgkinson, recorded in Clark's work on the Britannia Bridge, a long bar was loaded with varying weights, and the extension was found to be remarkably uniform up to 10 or 12 tons per square inch; being as nearly as possible $\frac{1}{12500}$ of the length for each ton. Beyond this strain the proportion failed, and the extension increased rapidly.

The degree of pliability varied, however, very much in different kinds of iron, even more than the ultimate strength.

Mr. Hodgkinson believed that a certain defect of elasticity was shown by permanent set, but this was very slight when the weight was small. For example, up to 6 tons per square inch, the permanent set appeared to be $\frac{1}{114}$ of the extension; with 9 tons it became $= \frac{1}{80}$ of the extension; and with 12 tons

$= \frac{1}{12}$ of the extension. But some doubt has been thrown* on the accuracy of these results, which, it is believed, may have arisen either from error of the apparatus, or from accidental irregularities of texture. General Morin has tried other experiments, which lead to a strong belief that no such defect is manifested in good material.

We may therefore be justified in concluding that for moderate strains (say, not exceeding 10 tons per square inch) we may assume the elasticity of wrought iron to be sensibly perfect in a practical point of view.

169. Beyond 10 or 12 tons the extension became rapid and irregular; nearly the whole extension became permanent; in fact, the limit of elasticity having been exceeded, the ductility came into play. The *ultimate* strength proved to be upwards of 20 tons, but the safe load for the use of the material was clearly defined by the limit of elasticity.

Mr. Styffe, in Table IV., gives some experiments which make the limit of elasticity vary from about 0·5 to 0·8 of the breaking weight, the mean being 0·625. This for 20 tons ultimate tenacity would give 12½ tons for safe load; but it would not be prudent to adopt, in practice, so high a proportion. One-half, or 10 tons, should be the outside.

170. Mr. Edwin Clark points out a curious result which he believes to exist in regard to the *permanent set*—namely, that it is *not increased by repetition, however often, of the same load.*

For example, suppose we have a very long bar of iron, which is quite new, and has never yet been strained, and let us put on a tensile force which will extend it, say, 3 inches

* See remarks by Professor Calcott Reilly in 'Min. Proc. Inst. C. E.,' vol. xxx., pages 258 to 263.

in length; then remove this weight, and suppose it will go back $2\frac{3}{4}$ inches, leaving $\frac{1}{4}$ inch permanent set.

If then we *repeat* the same strain, by putting the same force on again, the bar will only *come to the same place as before*, giving no further extension and no further permanent set.

The same thing is asserted of compressive action, as in the case of a column.

In some investigations I had lately occasion to make for the Government on breech-loading rifles, I found a fact had been observed at Enfield which was somewhat analogous. The spiral springs used in the Martini-Henry rifle had been found to become, in use, slightly weaker than when they were made, and it was at first feared that this was an evidence of want of permanent power in the form of spring. But on careful experiments being tried it was found that the relaxation was due to a slight permanent set, which occurred in the early use of the spring, but never afterwards increased. The evil was therefore at once cured by making the springs originally a little stronger than they were intended for—*i.e.* about 42 lbs. instead of 40 lbs., and then compressing them repeatedly before they were put in the locks. This brought them to the required strength, which they ever afterwards retained.

The effect of this property in practice is of considerable importance, as it shows that an iron structure will not increase in deflection by any number of repeated applications of the same load.

Suppose, for example, we have an iron girder bridge erected for carrying a railway over a road; and suppose, the first time a heavy train comes over it, it deflects 2 inches, and that when the train is passed over it returns 1·9 inch, leaving one-tenth permanent set. When the train comes over again it will deflect *only this* 1·9 *inch*—*i.e.* it will go

no lower than it did before, and this over and over again, as long as we please. If it were not for this property the bridge would go on taking more and more permanent deflection every time the load passed over, which would, at length, amount to something considerable.

In consequence of this curious property it is sometimes said that iron has the anomalous property of being *stronger after it is strained* than it was before. Of course this would be nonsense as regards the ultimate strength; all that it means is, that after iron has been once strained it will yield *less* under the same pressure; it will become stiffer or less pliable; and its elasticity will become more perfect under repetition of the same load.

It will be instructive to mention a case that occurred some time ago, where this principle was practically applied to great advantage.

You have probably heard of the process of drawing lead tube by forcing it, in a semi-fluid (or sometimes in a nearly solid) state, through a small annular hole. The lead is contained in a cylinder and pressed upon by a piston, and the force required is enormous, amounting to 50 or 60 tons per square inch. The practical difficulty of getting any cylinder to withstand the pressure was almost insurmountable. Cast-iron cylinders, 12 inches thick, were quite useless; they began to open in the inside, the fracture gradually extending to the outside, and increased thickness gave no increase of strength.

Cylinder after cylinder thus failed, and the makers (Messrs. Easton and Amos) at length constructed a cylinder of *wrought iron* 8 inches thick. After using this cylinder the first time, the internal diameter was so much increased by the pressure that the piston no longer fitted with sufficient closeness. A new piston was made to suit the enlarged cylinder, and a further enlargement occurring again and

again with renewed use, the constant requirement of new pistons became almost as formidable an obstacle as the failure of the cast-iron cylinders. The wrought-iron cylinder was on the point of being abandoned, when Mr. Amos, having carefully gauged the cylinder, both inside and out, found, to his surprise, that although the *internal* diameter had increased considerably, the *exterior* retained precisely its original dimensions. He consequently persevered in the construction of new pistons, and found ultimately that the cylinders enlarged no more, and so the last piston continued in use for many years. Here, therefore, the permanent set operated first in the internal portions of the metal as they expanded; it was then gradually extended to the surrounding layers, and so, at last, sufficient material was brought into play, with *perfect elasticity*, not only to withstand the strain, but to *return back* to the normal state every time after its application; and thus, by the spontaneous and unexpected operation of what was then an unknown principle, an obstacle, apparently insurmountable, and which threatened at one time to render much valuable machinery useless, was entirely overcome.

The same thing has been since found with the modern wrought-iron guns, which, when first used, expand slightly under the strain, but which soon acquire a permanent set, and do not then go farther.

In cast iron, the same principle accounts for the result I have mentioned in regard to cast-iron beams—*viz.* that it has been found that, provided the strain be moderate and well within the practical elastic limit, the repetition of the strain for a very great number of times has no perceptible effect in weakening the beam; in fact, the first application of the strain having produced a certain *permanent set*, this is not increased by repetition, but the beam, under this strain, acquires increased elasticity and receives no further injury.

171. The pliability and elasticity of wrought iron under *compressive* strain have been determined by Mr. Hodgkinson, who subjected to this kind of force long wrought-iron bars (prevented from bending by mechanical means), and carefully measured the effects with different weights.

It was found that *every ton* added compressed the bar very uniformly about $\frac{1}{10000}$th of its length, and that this uniformity continued up to about 13 tons. But beyond this, 1 ton more compressed it nearly $\frac{2}{10000}$ths, and the second ton nearly $\frac{4}{10000}$ths. In fact, about this point the compression kept on increasing, even while the weight remained the same.

This appears to be a little more alteration than is given by the tensile action; but possibly the quality of the iron, or some other accompanying circumstances, may have varied, and the number of direct experiments on the subject are not very large.

At any rate, the two series are sufficiently near to warrant us in assuming, for practical purposes, that up to the limit within which wrought iron ought to be used in structures, whether in tension or compression, we may assume its elasticity as practically perfect.

172. As to the value of the modulus of elastic stiffness, E, the tensile experiments I have mentioned give it = 12,500 tons.

The compressive experiments = 10,000.

Other experiments, by other parties, range from 9000 to 14,000.

But it has been generally assumed that the round number 10,000 may be taken as a fair mean value, easily remembered, and sufficiently near for ordinary practical purposes. The dimensions for this constant must be taken in inches and the weight in tons.

173. Mr. Styffe gives the following as the results of his experiments on elasticity :—

The elastic force which iron and steel develop on stretching is not always equally powerful in the same material, but is dependent on the manner in which the metal has been previously treated. Thus, by such mechanical operations as stretching, hammering, &c., the elasticity may be diminished, whilst by a moderate heat, or still better by a glowing heat, it may be increased. Moreover, it does not vary to any great extent for different kinds of material, but it generally decreases with the specific gravity. The measure of this force, or the modulus of elasticity, may be estimated in round numbers at nearly 14,000 tons for rolled or forged bars having a specific gravity of about 7·8, and containing only a trace of phosphorus; but for iron bars in which the material is very cold-short, or contains a considerable proportion of slag, it is only about 12,500 tons. On the contrary, in Bessemer iron with a specific gravity of 7·88, the modulus of elasticity may rise to about 15,000 tons.

Ductility.

174. I now come to a most valuable quality of wrought iron; *i. e.* its *ductility.*

When the elastic power of wrought iron becomes exceeded by the strain upon it, the change of its form becomes permanent; and, if the iron is good, this permanent change will go on increasing to a considerable extent, before rupture takes place.

In our 1-inch square bar, for example, strained by a weight hung at the bottom of it, we have seen that beyond 8 or 10 tons per square inch, the material has no longer power to recover itself completely, and the permanent set increases rapidly, the bar becoming gradually extended, or *drawn out*, more and more till it breaks. This effect is due to the *ductility.*

The ductility of iron may be accordingly estimated by what is called its *ultimate extension; i. e.* the amount it will stretch under direct tensile strain (gradually applied) before breaking.

Suppose our 1-inch bar to be loaded as before, a certain length of it is carefully marked off and measured before the weight is put on; the distance between the marks is then again measured from time to time, as the weight increases; and, last of all, when the bar breaks, the ultimate elongation taken in proportion to the original length will represent the ductility.

175. Mr. Kirkaldy tried this with many different kinds of iron, and found the results very variable.

In some kinds of iron the ultimate elongation was as much as 30 per cent., or $= 0\cdot 33$; in others it was as low as 3 per cent. $= 0\cdot 03$, the highest class irons being generally the most ductile, and *vice versâ.*

The general mean for all the bar irons tried was about 20 per cent., or $= 0\cdot 2$.

The *rate* of extension was not uniform (like elastic pliability) in proportion to the weight applied. It increased more rapidly as the weight became greater (in the same manner as the permanent set), so that the elongations of the bar became more and more rapid as weights were added.

And towards the last, as already mentioned, with the more ductile irons, the metal suddenly drew out in one place, and broke by the diminution of the area.

In the hard, brittle, and coarser kinds of iron, however, little or no indication was given of the approaching rupture; on the contrary, they gave way suddenly and unexpectedly.

176. Mr. Styffe gives the following results as to the ductility of wrought iron:—

With six kinds of Swedish iron tried, the maximum elongation was nearly 23 per cent.; the minimum, $16\frac{1}{2}$ per cent.; the mean, 20 per cent.

Specimens of Welsh rails elongated from 3 to $8\frac{1}{2}$ per cent.;

of Cleveland iron, 14 to 18 per cent.; of Staffordshire iron, 7 to 12 per cent.; and of Low Moor iron, 10 to 20 per cent.

He adds (Art. 33) the following remarks:—

> The amount of permanent elongation produced by stretching iron and steel is dependent, not only on the chemical constitution of the material, the manipulation to which it has been subjected, and the regularity of its section, but also on the method by which the traction is effected. These elongations generally increase more rapidly than the excess of the loads above those at the limit of elasticity; but it may be assumed that they are approximately proportional to this excess.

177. The most popular notion of the use of *ductility* is to enable the metal to be drawn into wire. But this, though no doubt a considerable advantage in iron, is by no means the greatest value of the quality. It is the *ductility* of iron which gives it the general power of *yielding*, bending, drawing out, or giving way under sudden strains, instead of snapping off; it is, in fact, the opposite of *brittleness;* as generally speaking, the least ductile iron will be likely to be the most brittle.

There is a word in great use popularly in describing iron, namely, *toughness.* Almost everybody knows, practically, what this means, but it is somewhat difficult to define strictly.

It is a sort of combination of tenacity, hardness, and ductility, the latter, however, being decidedly the chief element. And I need hardly remind you that this quality of toughness is, perhaps, the most important of all the properties of wrought iron as applied to modern use; for it is this that dictates the special adaptability of the material to railways, machinery, armour defences, and generally all other purposes which require not only strength, but also capability to resist shocks, concussions, and sudden and irregular strains.

I am not aware that there is any positive measure of toughness, comprising all the qualities which enter into it; but we may obtain a tolerable approximation to it by what I

have called *Mallet's coefficient; i. e.* the quantity of *work* necessary to break a bar, as I have before explained to you. (See Art. 97.)

This is a direct compound of the tenacity and the ductility, being = half the breaking weight multiplied into the ultimate elongation.

178. Mr. Kirkaldy's experiments give us the values of this coefficient as deduced from many kinds of iron.

For bar iron we find the maximum (best Yorkshire) = 9500. The minimum, a Scotch iron, = 730.

For the mean of the bar irons tried we may take it as = 5600.

Hardness.

179. The next quality we have to consider is the *hardness* of wrought iron.

This, also, like every other quality, varies exceedingly. Some kinds of wrought iron are almost as hard as unhardened steel, others are almost as soft as copper.

And this is fortunate, for we sometimes require one grade, sometimes another. Whenever wrought iron is subject to wear, or in those cases where permanence of shape is desirable, then a hard iron is the proper thing; but in other instances, where it is required to withstand blows, vibrations, or concussions, without danger of fracture, then softness is preferable. In the case of armour plates, for example (as I have before had occasion to remark), softness is the quality we have sought to obtain more than any other.

180. To some extent softness is allied to ductility, for it stands to reason that soft iron will generally be more ductile than hard; but this must not be received without qualification, for, on the one hand, in fine qualities of iron

a good degree of hardness may coexist with considerable ductility, while, on the other hand, some inferior soft irons may, from their want of strength and tenacity, fail in ductile capability.

181. The hardness of an iron does not, taken alone, give any index to its general goodness of quality. We might take the poorest Welsh rails and find them the same hardness as the best Yorkshire tyres, although the former may have cost only *5l.* a ton, and the latter *25l.*

182. I am not aware that wrought iron has been subjected to any direct graduated tests for hardness, such as those applied to cast iron by the American experimenters. These engineers did indeed try one piece of wrought iron, which they made = 3·32, but the range of hardness in different samples would probably be quite as large as in cast iron.

Texture.

183. A very good index to the hardness or softness of wrought iron, as well as to its character generally, is furnished by the nature of its *texture*, as evidenced by the appearance of its fracture.

Dr. Percy (page 8) has some excellent and instructive remarks on the internal texture of iron, from which the following extracts will be interesting:—

After fusion, iron is highly crystalline, and its surface will always exhibit distinct crystalline markings when slowly acted on by dilute hydrochloric or sulphuric acid. The crystallization of iron has excited much attention, especially amongst engineers, and although much has been talked and written about it, yet no small confusion respecting it still prevails. However, a careful examination of the subject will tend to remove this obscurity.

Bar iron acquires a largely crystalline structure by long exposure to a temperature which, though high, is yet very far below the melting point of the metal. On the application of a certain amount of heat,

the particles have sufficient freedom of motion to arrange themselves in crystals. Iron which has been frequently and strongly heated, or iron which has been forged into large masses, and which must necessarily have been subjected during a considerable time to a high temperature, tends to become largely crystalline in structure. The operation of hammering iron while strongly heated, and during cooling to a certain degree, will obviously interfere with the action of the forces which determine crystalline arrangement, and may, consequently be expected to diminish the size of the crystals. But in the case of large masses it will be difficult to affect the metal far below the surface, unless a very heavy hammer is employed and very powerful blows are applied, and even then it is hardly possible to conceive that uniformity in the size of the crystals should be produced through the mass. For when the exterior may be cooled down to redness, the interior must still be at a much higher temperature, it may be white hot; so that on subsequent cooling, after the cessation of the blows, the particles in one part of the mass will be in a condition to assume a more largely crystalline structure than those in another part. It is this which constitutes the difficulty in large forgings, and it cannot be overcome by continuing the hammering until the metal in the interior is sufficiently reduced in temperature to prevent the formation of large crystals in that part; for if the metal on the exterior were hammered at too low a temperature, as would certainly be the case in the condition supposed, it would become brittle and tender. The presence of phosphorus favours the formation of large crystals, and this element occurs in most commercial varieties of British iron.

The larger the crystals, the more easily will the iron break; for as fracture will occur in the direction of least resistance, which is that of the cleavage planes and of the planes of junction of contiguous crystals, it will be facilitated in proportion to the size of those planes. On the other hand, when the crystals are comparatively small, they are, so to speak, more interwoven with each other; there are no large cleavage planes, and consequently there is less tendency to fracture. Whether the foregoing considerations be correct or not, it is well established in practice that largeness of crystal in a bar of iron indicates facility of fracture.

When a piece of iron which has been melted, and which is largely crystalline, is cautiously hammered at a suitable temperature into a shape adapted for rolling, and then rolled into a bar not too thick, it will present either a fibrous or a crystalline fracture, according to the manner of breaking it, and especially the duration of the act. After nicking it to a slight depth on one side with a cold chisel, and then

bending it slowly backwards from the line of the nick, the fracture will be highly fibrous, and may be almost silky.* On the other hand, if it be nicked all round and afterwards suddenly broken in the line of the nick, the fracture will be crystalline with, it may be, only here and there an indication of fibre.

By the operation of rolling, the crystals are drawn out *in one direction* into wires, as it were, and the resulting bar, therefore, will be composed of parallel and continuous bundles of such wires. But the crystalline structure is not thereby obliterated, the crystals having been merely elongated; and accordingly every bar, even down to the smallest size, should on sudden transverse rupture present a crystalline fracture, the appearance of which will become indistinct in proportion to the extension of the crystals, or, in other words, to the degree of rolling. In the process of wire drawing, the same result should occur; and the fracture, even of the finest wire, when suddenly effected, should be crystalline, though it may be very minutely so.

Time plays a most important part in determining the character of the fracture. When the metal is broken with extreme rapidity, there is no time allowed for the exercise of the property of ductility, and the fracture will necessarily be crystalline; but on the contrary, when rupture is slowly produced, there is ample time for the exercise of that property, and during the act of bending a bar in order to break it, the crystals on the convex side in the place of flexure actually undergo a process equivalent to wire drawing, and so tend to develop fibre on fracture. However, in every rolled bar it has been shown that fibres in the form of elongated crystals pre-exist. Hence the fibrous fracture of a bar of rolled iron is partly the result of the operation of bending, and partly of that of rolling.

In a rolled bar of iron the fibrous structure may be rendered manifest by the etching action of acids, as is the crystalline in a piece of iron which has been melted, and for precisely the same reason.

In an ordinary rolled bar of iron there is another cause inducing the manifestation of fibre by this etching action. There is always some silicate of protoxide of iron remaining in such a bar, and this becomes extended along with the iron during rolling; as acids do not act on this silicate and the metallic iron with equal intensity, it is clear that their solvent action will cause the appearance of fibre. This silicate is apt to be irregularly diffused, and to occasion corresponding irregularity in the etching process, deep furrows and holes having frequently been the result.

* *i. e.* if the quality of the iron be fine; but I do not believe that a silky fibre can be produced by any means from inferior iron.—W. P.

184. I will only add on this subject a few general indications as to how the texture of iron is usually considered in a practical point of view.

There are two distinct kinds of texture observable in the fracture of wrought iron, *viz.* the *crystalline*, and the *fibrous*, and there are certain *general* interpretations of these appearances which, though subject to many exceptions and modifications in practice, are sufficiently near the truth to be prominently mentioned.

A *crystalline* fracture is generally considered indicative of *hardness.*

If the crystals are *fine* and uniform (or, as it is often expressed, if the iron is *fine-grained* or shows a "saccharoidal" fracture) it is indicative of considerable tenacity, and of a high general quality. And great tenacity is indicated by a particular irregular *tearing* appearance, caused by the strong effort of the fine crystals to hang together.

If, however, the crystals are *coarse and large*, they will probably be easily separated, and the iron (though still hard) will be wanting in tenacity, and brittle, and generally of low quality.

On the other hand, *stringy or fibrous* fracture is, generally speaking, considered indicative of *softness* and ductility.

If the fibres are *fine and silky*, the iron is usually not only soft, but tenacious, and generally of high quality in other respects. But if they are *coarse and rough*, the iron, though still it may be soft, is wanting in tenacity, and of low quality and value generally.

But these directions must not be received as infallible, for the reason given by Dr. Percy, that the fracture of the *same iron* will often differ when broken under different circumstances. The appearances will vary according to the degree of suddenness, or the reverse, with which the iron is broken. If it is snapped suddenly, there is always a greater tendency to a crystalline fracture, whereas if it is broken slowly, by a

gradual application of the breaking force, the tendency is to show fibrous structure. This is explained in the following way.

The *fibre* in iron is produced by *rolling*, which appears to have the effect of causing the particles to arrange themselves in what may be called bundles of threads, parallel to the length of the bar, as it goes through the rolls. The more iron is rolled, the more marked and positive is the fibrous structure; and it is believed that this fibrous structure can be given in this way, to a certain extent, to almost any kind of iron, although of course some kinds will take it much more perfectly than others. Hence arises the effect of repeated rolling in making iron *tough*, which is the result of a fibrous structure in good iron.

Now if we take this bundle of threads, and break it off suddenly and short at right angles, we shall see in the fracture *only the cross-sections* of the different threads, which are in reality elongated crystals, and this will give it a crystalline appearance.

But if we break it more slowly we give it the opportunity of *bending* as it *breaks*, and instead of breaking off at right angles, we shall get the threads drawn out, which will enable us to see the *sides* of them, showing a *fibrous* fracture.

The two kinds will frequently be *mixed* in one piece, and this is often promoted by some portions of the iron being harder than others, the harder portions breaking more suddenly than the softer, and showing more crystalline.

In iron that has been *piled*, the different layers often break differently, from this cause.

This difference may also be caused sometimes by altering the shape of the iron, so as to make it snap more easily, as by *nicking* it, which will tend to make it look more crystalline. In fact, it has been conjectured that the act of nicking may tend to crystallize the iron immediately adjoining.

It is sometimes even asserted that *any iron* may be made to look either crystalline or fibrous in the fracture, according to the way in which it is broken, and that therefore no correct inference can be drawn. But this is not the case.

Nicking a bar, for example, and then breaking it by a blow, is the usual way of trying iron in the workshop; and though this undoubtedly tends to produce crystalline fracture, yet it cannot conceal a good tough, truly fibrous structure, which I have found exemplified in this way over and over again.

Again, in the iron plate experiments at Shoeburyness, when a plate was struck by a ball flying at 1600 feet a second, surely this would be about the maximum of suddenness with which the fracture could take place, and yet in the best and softest irons more lately made, fibrous fracture has been always very marked, mixed, however, generally with portions of crystalline.

I do not, however, conceal from you that, to judge properly of the quality of iron by its fracture, requires very considerable *experience*, which no other kind of teaching can efficiently supply.

185. There is another kind of variation in the texture of iron which deserves a remark or two, as it often affects the structural use of the metal; this is a certain kind of *brittleness* (or as it is called, *shortness*), which varies under different conditions of heat.

Some kinds of iron are very tough and fibrous when cold; but when they are at a *red heat*, the cohesion of the particles seems to suffer, and the metal becomes brittle and almost rotten. The iron is then called *red-short;* and of course it is difficult to work in the forge so as to keep it sound.

On the other hand, other kinds of iron are perfectly ductile and malleable, as well as cohesive, when heated; and will therefore work excellently in the forge, but become

brittle and fragile when cold. This is called *cold-short* iron.

Red shortness is, I believe, said to be due to the presence of sulphur; cold shortness to phosphorus: the defects are very common, and users of iron must be prepared often to meet with them.

Where extensive and complicated forging operations are necessary, red-short iron is inadmissible, but where the forms are simply obtained, and where toughness in use is an object, it will answer well.

On the other hand, cold-short iron must be avoided whenever the material has to stand blows or concussions, for which its brittleness would prove a disqualification.

Specific Gravity.

186. Wrought iron is considerably more dense than cast iron. Its specific gravity varies according to the quality, the best iron being usually the densest, as in consequence of the amount of *working* it has received, the particles have become pressed closer together, and the lighter impurities more perfectly excluded.

Dr. Percy gives the sp. gr. of *pure* iron, obtained by electro deposit, as 8·14, but no wrought iron in practical use ever approaches that figure.

The large collection of samples tried in Mr. Kirkaldy's experiments ranged between 7·5 and 7·8.

I myself have found iron rails vary from 7·47 to 7·64, giving a mean of 7·54. But these are generally of a low quality of the material.

It is found that (as we have already seen in the case of cast iron) the sp. gr. furnishes a fair index of the general quality of the material. If it approaches 7·8, it will generally be found to have good qualities of some sort

or other; if it is nearer 7·5, it will probably not have much to recommend it.

187. It is usual in practical calculations to assume the sp. gr. of wrought iron to be 7·68, as this is a fair average value, and it affords some very great conveniences in estimating weights, particularly as regards *plates* and *bars*, the two kinds in most common use.

On the assumption of the above specific gravity, the weight of a cubic foot will be 480 lbs.; and consequently the weights of iron plate will be as follows:—

		lbs.	
1 inch thick	.. .. ..	40	per foot super.
$\frac{3}{4}$	,, ...	30	,,
$\frac{1}{2}$	,, ...	20	,,
$\frac{1}{4}$	,, ...	10	,,
$\frac{1}{8}$	,, ...	5	,,
$\frac{1}{16}$	,, ...	$2\frac{1}{2}$	,,

and so on; a most convenient rule, which is not easily forgotten when once it is known.

Then in regard to *bars* of all shapes, square, round, flat, angle iron, deck beams, T irons, and all sorts of shapes which run in long lengths, we have another easy rule, founded on the same assumption of the sp. gr.

The weight of a cubic inch will be—

$$\frac{480}{1728} = \frac{10}{36} = 0 \cdot 28 \text{ lb.}$$

Consequently, a bar 1 *inch square* and 1 *yard long* (containing 36 cubic inches) will weigh 10 *lbs.*

Hence, to find the weight of a wrought-iron bar of any section, we have only to *multiply the number of square inches in the section by* 10, and that will give us the weight of 1 *lineal yard* of that bar.

Miscellaneous Remarks.

188. Before quitting the subject of wrought iron generally, there are a few other points affecting its structural use which deserve mention.

In the outset, speaking of the tensile strength of wrought iron, I remarked that the strength varied as the area of the cross-section, *i.e.* that a bar 2 inches square would have four times the tenacity of a bar 1 inch square.

This is quite true, if we suppose the iron to be of the *same quality* throughout, in both the bars.

But there is a fact which I must now explain to you, which considerably affects the application of this rule in practice, namely, that the quality of iron made from the *same original material* will vary considerably, according to the *size* in which it is produced, being generally inferior in the larger and superior in the smaller sizes.

Thus, if we were to take the same puddled bar, and work three portions of it, one into say a large hammered shaft, another into a rolled bar 1 inch square, and the third being ultimately drawn into wire; we should find considerable variations in the strength and other properties of the three, increasing in the smaller dimensions. I have mentioned a similar fact in regard to cast iron.

The data of strength and other properties I have given have been derived from bars which we may consider the medium or most common dimensions of marketable wrought iron.

I may now say something of the variations from these sizes, first as regards *larger*, and secondly as regards *smaller* dimensions.

Large masses of wrought iron are usually made by hammering, although of late years rolling has been applied on a much larger scale than formerly. But whichever process

is adopted, it is found that when the mass is large, the texture of the iron, particularly in the central portions of the mass, cannot be brought into a state to give such good results, either of strength or ductility, as in smaller dimensions.

Mr. Mallet has investigated this subject thoroughly, and explained clearly how the effect occurs.

It would appear that the iron having assumed a tendency to crystallize by the great heat, the effect of the blows of the hammer, or the pressure of the rolls, cannot be made to penetrate so far through the mass of the material as to diminish sufficiently the size of the crystals or to produce fibrous texture, and so to gain the strength and toughness that are easily obtained in smaller pieces.

And further, in the cooling of such large masses, it is believed that from the retention of the heat in the centre of the mass, after the outside has *set*, the former will be in a position to *assume* a large crystalline structure, even if it did not possess it before. Moreover, it has frequently been found that the contraction of the interior in very large forgings, after the outside has set, has actually produced hollows or unsound places, just as in masses of cast iron.

It is this which constitutes the difficulty in large forgings; it cannot be overcome by longer continuance of the hammering, which would damage the cooled exterior. Nor can it be altogether disposed of by increasing the weight of the hammers, as the alteration due to cooling would still always be present.

It is often supposed that the texture in a large mass can be determined by that of the bars or small pieces piled up together to form it; as, for example, when bars of rolled and fibrous iron are piled up together, or *faggoted*, to form a large bloom, afterwards hammered or rolled into shape.

But this is an error, for the high welding heat to which

the mass must be subjected, before it is worked, tends to obliterate the former texture, rearranging the molecules afresh, in a crystalline form.

Mr. Mallet (in a paper published in vol. xviii. of the 'Minutes of Inst. C. E.') has given some remarkable facts to illustrate the comparative weakness and irregularity of large forgings.

He cut pieces from large masses of wrought iron prepared in several different ways, but all alike in original composition, and he tested them by tension, obtaining both their ultimate tenacity and their ductility or ultimate elongation. Taking then the original bars which had been piled or faggoted to form a large forging, and comparing them with specimens cut from the forging itself, he found the following results:—

	Tenacity.	Ultimate Elongation.	Work of Rupture.
Original bar	21·9	0·055	1347
Pieces taken from large forging ..	19·5 to 16·4	0·043 to 0·006	870 to 118

One specimen, cut transversely from the end of a very heavy cylindrical forging, which had been exposed to heat and percussion for nearly six weeks, gave a tenacity of only $6\frac{1}{2}$ tons per square inch, or less than the average strength of cast iron;—giving also an ultimate elongation of 0·0035, and the *work* of rupture only = 31·9; all less than cast iron.

Mr. Mallet obtained the modulus of elasticity from these large forgings only from 5600 to 8075, showing the metal to be inferior in stiffness, as in tenacity and ductility.

Mr. Kirkaldy also tried specimens cut from large forgings, and the fractures showed great irregularity of structure, with sometimes small tenacity and ductility.

In one case, a piece cut from a crank shaft gave :—

Tenacity	14·5
Ultimate elongation	0·025
Work of rupture	407

Another from an armour plate gave :—

Tenacity	15·4
Ultimate elongation	0·047
Work of rupture	825

189. While on the subject of large masses of wrought iron, I may say a word or two as to the huge plates which have lately come into extensive use for iron armour for war vessels.

When the Iron Plate Committee (of which I had the honour to be a member) were first appointed, they began by instituting a series of experiments to test the comparative strength of plates of different thicknesses, and they early discovered the inferiority of large masses as compared with small. They, however, urged upon the makers the necessity of using every endeavour, by powerful machinery, and otherwise, to improve the quality, and the result has been very satisfactory, for plates were at last obtained of 5½ inches thick, as good as the 3 or 3½ inch plates were five years before.

The Committee obtained, by testing various samples cut from the best plates, of 4½ and 5½ inches in thickness, a mean of about—

	Tons.
Tenacity	24
Ductility (ultimate elongation) ..	0·211
Work	5670

Which it will be seen is equal to the averages obtained from bars.

The question occupied a good deal of the Committee's

attention whether these large plates were best made by rolling or hammering; some makers preferring one mode, some the other.

Good plates had been manufactured by either process. But some essential differences appeared between them. It was found, for example, that rolled plates could be made much *softer* than hammered ones; the rolling process induced a fibrous structure, and this gave ductility and softness to the iron, which was such an essential requisite for armour plates as to have practically settled rolling as the most approved mode of manufacture. In hammered plates no definite *fibre* was developed, and there was always a tendency to be hard.

But the rolling process, for large plates, was not without its disadvantages, as it was found so difficult to get the large layers of which the plates were made perfectly welded together.

Armour plates are, it is true, exceptional things; but I believe the same principle will be found to hold true in the comparison of rolled and hammered iron generally.

No doubt hammered articles may be made of very high quality; indeed the highest qualities to be found are produced in this way, as, for example, cranked axles of locomotives, which are the best iron it is possible to procure; but still, though these articles have special good qualities of their own, they do not possess the *soft* and *fibrous structure* that may be found in rolled iron of much lower price.

190. So much for masses of iron of sizes above the average. Let us now look to those *below;* and we shall find that wrought iron, when it comes to small sizes, appears to *gain strength* as it lessens in dimension.

Mr. Kirkaldy tried some experiments to determine to what extent the rule of access of strength by diminution of size was general. He first took various sized bars of the same commercial make, and found a general improvement

in the smaller sizes, though not very marked, or always uniform. He then cut several pieces of the *same bar* $1\frac{1}{2}$ inch round; which, after re-heating, were rolled down to smaller sizes. The breaking weights were—

		Tons.
When made	$1\frac{1}{4}$ inch	25·5
"	1 "	25·7
"	$\frac{3}{4}$ "	26
"	$\frac{1}{2}$ "	26·6

But the increase of tenacity becomes much more marked when the iron is reduced to the still smaller state of *wire*. This is made of iron of very good and ductile quality, *drawn* down (as it is termed) by pulling it through holes in a steel plate till it reaches the size required. This is done cold, the wire being frequently *annealed* during the process. Iron wire is of considerable importance in construction, on account of its large use abroad for suspension bridges.

Muschenbröck's experiments, already mentioned, on iron wire $\frac{1}{25}$ of a square inch area, gave 30 to $37\frac{1}{2}$ tons tenacity.

Telford also tried experiments on iron wire from $\frac{1}{5}$ to $\frac{1}{20}$ in diameter, and obtained a tenacity of from 35 to 43 tons.

The wire for the Niagara Suspension Bridge (made in Manchester) from good charcoal iron, was found to break, on an average, with about 45 or 46 tons.

The wire for the Freiburg Bridge, made in Switzerland, also from the best foreign charcoal iron, stood above 50 tons.

I myself had occasion to make some experiments a short time ago, on steel pianoforte wire, which I found to bear the astonishing strain of from 100 to 120 tons per square inch; whereas the steel from which it was made would probably not have borne, in the state of bar, more than half that strain.

M. Morin * has given some experiments on the strength

* 'Résistance des Matériaux.' Paris, 1862. Vol. i., Art. 21.

of iron wire, made for the suspension bridge of Roche Bernard; it was a little over 3 millimètres (0·12 inch) diameter, and the breaking weight was about 80 kilogrammes per square millimètre, or above 50 tons per square inch. As it was suspected that long lengths would be less strong than short ones, owing to the greater chance of faulty places, lengths of the same wire of 2 mètres and 20 mètres respectively were tried against each other, but on the average no greater weakness in the long lengths appeared. M. Morin, however, adds this observation :—

But experience, and especially the numerous accidents which have occurred with wire bridges, have much modified the opinion in favour of wire, and without at present entering further into the discussion of the subject, the student should be cautioned not to place too absolute reliance on the results of the experiments here brought forward.

It has been found that wire is weakened by forcible binding with ligatures, or by sharp bending, ruptures having almost always taken place at these points; hence such causes of damage are to be avoided as much as possible in construction.

191. I have mentioned that in the manufacture of wrought iron the quality is improved by the *repeated working* it undergoes.

Mr. Clay, of the Mersey Steel Works, tried an interesting experiment to show this. He took some puddled bar, and piled it and rolled it repeatedly over and over again, for twelve successive times, and tried the tenacity each time. He obtained—

		Tons.
	Original state	19·6
	2nd working	23·5
	3rd „	26·6
Maximum	6th „	27·5
	9th „	26
	12th „	19·6

Showing that, beyond a certain point, repeated working acted prejudicially. No account, however, was taken in these experiments of the effect on the hardness or ductility of the iron. There is reason to believe that with good material the toughness is increased by repeated rolling.

192. I have told you that the inside portion of large masses of wrought iron is generally believed to be inferior quality to the outside portions. This notion has sometimes been pushed to the extent of believing that there is some peculiar virtue in the *external rough skin*, and some people will object to have this removed, for fear of weakening the piece.

In *cast iron* this idea is correct, the external skin being peculiarly strong; but experiments have not corroborated it as regards wrought iron, for bars of this material, turned or planed, have proved as strong as rough bars of the same metal and the same size.

This is fortunate, as wrought-iron work for machinery has generally to undergo much preparation of this kind, and it would be a pity if the quality of the material were deteriorated thereby.

193. Wrought iron has also frequently to undergo in the workshop the operation of *forging*. It is not found that this operation has any injurious influence on the strength, provided the metal is not overheated, or, as the smiths call it, *burnt*. In some cases the tenacity is improved by forging; for example, Sir M. Brunel tried best Yorkshire iron, reduced by hammering, and obtained 27 to 36 tons.

The effect, however, of hammering—particularly if continued till the metal is nearly cold—is to *harden* the iron, and diminish its ductility; sometimes, indeed, with indifferent iron, it will make it quite brittle. Dr. Percy explains this by remarking that when iron is hammered cold, especially in various directions, the crystals of which it consists will be-

come more or less disaggregated, and therefore the strength of the metal will be diminished.

Iron is also hardened by *cold rolling*, which is somewhat akin to wire drawing; and this is found (also like wire drawing) in some cases to increase the tenacity.

Mr. Styffe (Art. 33) says that "by cold hammering, cold rolling, and other forms of mechanical treatment applied at a low temperature, both the limit of elasticity and the tensile strength are increased, while by the same treatment the extensibility is diminished. In these respects heating produces an opposite effect."

Iron is also often found to become hardened by being heated and suddenly cooled in water. This is, strictly speaking, the property of steel; it is probable that pure iron would be free from it, and that when it occurs it is due to the presence of a small amount of carbon. The operation raises the strength and the limit of elasticity, but diminishes the extensibility.

In all these cases, however, of what may be called abnormal hardening, the effect may be removed by the process called *annealing; i. e.* heating the metal to a red heat, and allowing it to cool gradually, which appears to allow the particles to rearrange themselves in their normal position. Annealing is a process in constant use for wire drawing, cold metal rolling, and all other processes where artificial hardening has taken place, and where its effects require to be removed. Steel is softened in this way.

There is, however, no reason to suppose that the softness produced by annealing will ever go *beyond* the normal degree; *i. e.* no amount of annealing will ever convert a naturally hard iron into a soft one.

194. Wrought iron may be given a hard surface by a peculiar process called *casehardening*. This consists in sub-

jecting the article to a red heat for some days in contact with animal substances containing carbon—as bone-dust, leather scraps, &c. The effect is to convert the surfaces so acted on into steel, the nitrogen of the animal matters playing, it is supposed, an important part in aiding the conversion. Many parts of the locks of the small-arms made at Enfield are treated in this way; indeed, it is preferred to making them of steel.

195. An important question has been raised and often discussed, whether wrought iron is subject, by use, to deterioration of its quality.

Cases have occurred where wrought-iron articles, exposed to vibrations and concussions—as, for example, pieces of machinery, axles, crank shafts, girders, &c.,—have suddenly failed, after being at work for a long time, and without evidence of weakness or defect. And as it has often been found that in these cases the fracture has presented a crystalline appearance, a theory has been raised that the continued vibration has had the effect of altering the quality of the iron—transforming it from a tough and fibrous to a crystalline and brittle texture.

On this point Dr. Percy gives the following judicious remarks :—

The question will naturally suggest itself whether gentle vibration, the result of very frequently-repeated light blows, or of vibration without impact, caused by jarring, grinding action, or in an axle working in badly-lubricated bearings, or of straining and torsion in shafts, &c., very much less intense than would be produced by heavy hammering, would tend to induce permanent disaggregation of the crystals of iron and consequent tenderness. It is a question of great practical importance in reference to the use of iron, as in chains in coal-pits, and on railways, where the safety of human life is concerned. Opinions are divided upon it, and I am not acquainted with any precise experimental data, to justify any very positive conclusion on the subject. Many instances are recorded in which vibration is alleged to

have induced permanent brittleness; but if I be not mistaken, the iron reported to have thus deteriorated in strength has not, at least in many cases, been properly examined and tested. Changes in mechanical properties of the metal may have been attributed to vibration, which were in reality due to original and undetected flaws. In certain metallic alloys it is well established that vibration may cause great alteration in structure, and as a consequence, extraordinary brittleness; and decided instances of such alteration are recorded. But it may be objected that alloys are one thing, and a simple metal another and very different thing, and that although the former may be affected by gentle and sufficiently-repeated vibration, it by no means follows that this should be the case with the latter. Accurate experiments will alone determine the force of this objection. Nevertheless it seems reasonable to suppose that a simple metal like iron should be affected by exposure to the conditions in question. The expression gentle vibration is, after all, indefinite, and may include very different degrees of concussive action, and much may depend on a comparatively slight difference in the intensity of such action, especially when occurring at different temperatures comprised even within the comparatively narrow limits of ordinary atmospheric variation.

Another point remains to be considered, namely, whether vibration caused by impact or otherwise may induce a crystalline arrangement which did not previously exist, or was only imperfectly developed. I have not met with any evidence to justify an answer in the affirmative. All iron, after fusion, or after having been exposed to high temperatures sufficient to induce softening and pastiness, consists, as we have seen, of an aggregation of crystals. In the act of rolling, or extension of any kind, these crystals are elongated, but not obliterated, and they may always be rendered manifest by sudden fracture. Now, when a bar becomes brittle by hammering cold, there is no reason to suppose that this result is due to the actual development of a crystalline structure, for the loosening or disaggregation of the crystals originally composing the mass appears quite adequate to account for the brittleness. If such a bar had, previously to hammering, been broken under special conditions, so as to allow time for the exercise of the property of ductility, it would have presented a fibrous and not a crystalline fracture.

Neglect in observing the essential connection between the character of the fracture and the particular mode in which it has been effected, has led to the conclusion that the crystallization of iron has originated from mechanical treatment, when in reality crystalline structure preexisted, and was only rendered easily manifest by fracture consequent on induced brittleness.

The idea now under consideration has gone so far as to lead to the introduction of a word to express this peculiar action—viz. *fatigue* of metals, it being assumed that by constant slight motion the metal becomes fatigued or weakened.

The question is a difficult one, and its discussion rather belongs to the metallurgist than to the practical man. Dr. Percy appears, from the foregoing remarks, to consider such an action possible, but doubts whether any sufficient proof of it has yet been shown. And this is the view which I think most practical men take also. It is difficult to prove, in these cases of fracture, that any change has been caused by the use of the iron, for either the quality may have been inferior from the first, or the change in appearance may have been induced by some particular mode of fracture.

Mechanical experiment, so far as it has gone, discourages the idea of any such deterioration taking place, *provided the strain be within the elastic limits of the material;* for it has been found that, with iron thus moderately strained, the force and its consequent bending may be repeated and removed alternately for thousands, and even millions, of times without any apparent damage.

When, however, the strain *exceeds* this limit, deterioration of some kind will certainly follow its repetition, and probably this may have been the case in many of the instances in question.

But, even in this case, if the strain is *quiescent* it does not appear that the ultimate tenacity of iron is damaged by its being previously strained to an extent short of fracture. Mr. Lloyd, the chief engineer of the Admiralty, tried an experiment to ascertain the effect of four successive breakages of the same bar. He obtained, on the mean of several trials—

1st breakage	.. ..	23·94 tons per square inch
2nd "	.. ..	25·86 "
3rd "	.. ..	27·06 "
4th "	.. ..	29·2 "

This was good ductile iron, stretching about $\frac{1}{6}$ in length, and reducing considerably in lateral dimensions.

The *increase* in tenacity is, however, puzzling. It would seem that either the bar was much stronger in some places than others (the weakest giving way first), or that the *drawing* of the bar had added to its tenacity in a manner which has been proved to occur in wire drawing.

In all experiments on the tenacity of iron it is a necessary precaution to apply the strain gradually and slowly; and it does not appear that the time occupied in this is any material disadvantage to the result. If the heavier strains were applied *suddenly* there is no doubt that the iron would appear much weaker than it really is. Theory points out that the extension for impact is much greater than that for passive strain. Mr. Kirkaldy found, by actual experiment, that when the weights were suddenly applied, the iron bars broke with much less than their proper statical breaking load.

196. The effects of *variation of temperature* on wrought iron deserve a passing notice.

At a high heat there is no doubt that the molecular condition becomes changed, having a tendency to crystallize, in large crystals. Probably all iron, *before working*, takes this condition, the working reducing the crystals down to a small grain, or lengthening them out into fibre.

It is also very well known in smiths' shops that iron may be overheated in the forging, or *burnt*, as it is called, which develops large crystals and makes the iron weak and brittle. It is the duty of a good smith to guard against this, which is, of course, highly prejudicial.

The effects of more moderate heating on the strength have also been subjected to trial. Tredgold imagined that *any* amount of heating would reduce the cohesive force; but this opinion has been disproved. Sir Wm. Fairbairn tried speci-

mens of the same iron at different temperatures, from 0° to dull red, and found that up to 300° or 350° the tenacity remained stationary, or, in some superior irons, gradually improved; but beyond this it fell rapidly to a red heat, when, of course, the iron became comparatively weak.

When highly heated in forging operations, wrought iron loses substance by the rapid oxidation of the surface. At a white heat iron burns vividly, and at a lower heat it oxidizes more slowly. In forging and mill operations, under great heat, the surface becomes coated with scales of oxide, which may be, in a great measure, detached, either by bending or hammering the bar when cold, or by plunging it, when hot, into water. This is known as iron smithy-scale or hammer-slag. It is found to consist of a mixture of protoxide and sesquioxide, and contains from 70 to 76 per cent. of metallic iron. The *waste* formed by this scale is a matter always deserving of consideration in forging operations.

197. It is often supposed that extreme *cold* diminishes the tenacity of wrought iron; and it is certainly a fact that railway accidents occur more plentifully, by the breaking of tyres, axles, and so on, in frosty weather. Unfortunately, however, we have scarcely sufficient data on the subject to justify our ranking this among the established phenomena of the material.

Mr. Kirkaldy tried some few experiments, by forming a number of bolts out of the same bar, and testing them after exposing some of them to frost, while the others were kept warm.

It was found that when the strain was gradually applied there was very little difference; when *suddenly* applied the strength appeared diminished, but only 3 or 4 per cent. The bar was, however, of very superior quality; possibly with inferior iron the result might have been more marked.

Dr. Percy suspects that the concussive action may have a different effect at different temperatures, comprised even within the ordinary limits of atmospheric variation. He says—

The frequent accidents which occurred from the breakage of iron on railways a short time ago during the prevalence of a severe frost, are confirmatory of this opinion. Moreover it has been clearly demonstrated that the tenacity of iron varies considerably at temperatures not far remote from each other.

Mr. Styffe investigated this point by elaborate and carefully-conducted experiments, and arrived at the following conclusions (Chap. III., Art. 10):—

That the tensile strength of iron and steel is not diminished by cold, but that even at the lowest temperature which ever occurs in Sweden it is at least as great as at the ordinary temperature.

That at temperatures between 212° and 392° Fahr. the tensile strength of steel is nearly the same as at the ordinary temperature, but in soft iron it is always greater.

That neither in steel nor in iron is the extensibility less in severe cold than at the ordinary temperature, but that from 266° to 320° Fahr. it is generally diminished, not to any great extent, indeed, in steel, but considerably in iron.

That the limit of elasticity in both steel and iron lies higher in severe cold, but that at about 284° Fahr. it is lower, at least in iron, than at the ordinary temperature.

That the modulus of elasticity in both steel and iron is increased on reduction of temperature, and diminished on elevation of temperature, but that these variations never exceed $\frac{1}{20}$ per cent. for a charge of 1·8° Fahr., and therefore such variations, at least for ordinary purposes, are of no special importance.

Mr. Styffe admits the fact that iron articles used on railways are found in practice to break more readily in frosty weather; but he attributes this, not to any alteration of the iron, but to the general increased hardness of the road, by which the force of the shocks is greatly increased.

The translator of Mr. Styffe's work, Mr. Sandberg, being led by his experience to be somewhat doubtful as to the

sufficiency of his author's conclusions, obtained permission from the Swedish Government to try some further experiments on the action of cold, and he records the results he arrived at in the following terms :—

> That for such iron as is usually employed for rails in the three principal rail-making countries, Wales, France, and Belgium, the breaking strain, as tested by sudden blows or shocks, is considerably influenced by cold, such iron exhibiting at 10° Fahr. only from $\frac{1}{4}$ to $\frac{1}{3}$ of the strength which it possesses at 84° Fahr.
>
> That the ductility and flexibility of such iron is also much affected by cold; rails broken at 10° Fahr. showing on an average a permanent deflection of less than 1 inch, whilst the other halves of the same rails, broken at 84° Fahr., showed a set of more than 4 inches before fracture.
>
> That at summer heat the strength of the Aberdare rails was 20% greater than of the Creusot rails, but that in winter the latter were 30% stronger than the former.

Mr. Sandberg conceives that the presence or the quantity of phosphorus in the iron may considerably affect its behaviour under low temperatures, so that some irons may give very different results from others.

198. Everybody knows the liability of iron to become *rusty* by exposure to wet, and this action is of much importance.

At the ordinary temperature water has no action on iron, even in the most finely-divided state, *provided air be excluded.* When, however, it is exposed to the conjoint action of air and moisture, rusting occurs. The rust of iron is hydrated sesquioxide.

Wrought iron is more subject to deterioration by rust than cast iron, the combination with carbon appears, in some measure, to act as a preservative.

199. For this reason some means must always be adopted for efficiently *protecting* wrought-iron work from rust in all exposed situations, or it will soon be destroyed.

And there are two means in common use for this purpose. The first is what is called *galvanizing*, a very improper name, merely derived from a process by which it was proposed to be done, but is *not* done. Galvanizing means nothing more than covering the surface of the iron with a layer of *zinc*, which, being much less liable to oxidation, protects the iron below. The process is very simple: the iron has its surface cleaned by dilute acid, and is then dipped into a bath of melted zinc, which adheres so strongly to the iron as to form almost one substance with it. The process is, in fact, analogous to that of making *tin plate*, or *tinning* the insides of saucepans.

The most extensive use of the zinked iron is for corrugated sheets for roofing and for telegraph wire; but it has lately been also much and successfully used for other and larger articles, particularly for ships' bolts and other ships' fittings.

It has been sometimes thought that the zinking process interfered with the strength of wrought iron, and Mr. Kirkaldy tried some experiments to determine this. He took strips of plate of different makes, and of thicknesses varying from $\frac{3}{16}$ to $\frac{3}{8}$, some of which he zinked, while fellow-pieces were kept plain. These were tested for tenacity, and the results showed no difference, between the zinked and the unzinked plates, greater than the slight variation due to different parts of the same sample.

But, of course, it is only in comparatively few cases that this zinking process can be applied. The more common way of protecting ironwork is by covering it with *oil paint*, which, if well and efficiently done, is a very fair protection against ordinary atmospheric conditions of wet and moisture. Several coats of paint must be applied. The iron should first be cleaned, and then painted well and carefully over with a first coat of *red-lead* paint, made very *thin*, with the

object of first covering the iron well in every part, and getting the paint into every nook and cranny; when this thin coat is dry it forms a good tenacious base for future coats, of which two or three more, now made much thicker, should be added, each coat being allowed to dry before the new one is laid on.

Several kinds of paints are used, and many so-called patent *anti-corrosive* nostrums have been proposed; but I am not aware that anything has been found to answer better than ordinary lead paint of good quality.

Bright ironwork, such as the fitted parts of machinery, &c., which is required to be sent abroad, and may be exposed on the voyage to the action of water, is often covered with a mixture of white-lead and tallow, the former being added to give consistence to the latter, and prevent it from melting and running off under heat. Dr. Percy recommends, for the same purpose, common rosin melted with a little Gallipoli oil and spirits of turpentine. The proportions, which may easily be found by trial, should be such as will make it adhere firmly and not chip off, and yet admit of being easily detached by cautious scraping.

Iron structures, if well painted, will be protected for a short period; but the painting must be *carefully watched* and *often renewed* from time to time, or the insidious oxidation will creep in.

200. The necessity for this has led to a practice which has, indeed, become a most important principle in the design of all iron structures, particularly those of wrought iron—*i. e.* so to lay them out that the whole of the surfaces exposed to atmospheric action shall be *easily accessible* for the purposes of examination and painting.

If any parts cannot be got at freely, they will assuredly be destroyed in a few years.

All railway engineers who understand their business take great pains to make their iron bridges conform to this condition. In the well-known Britannia Bridge the cells of the top were made of such a size that a person could creep through them to examine and paint the insides; and cells were introduced for this express purpose in the *bottom*, where otherwise they would have been unnecessary.

201. It is also desirable, in structures much exposed, not to have any wrought-iron parts *very thin*. Strength that would be sufficient for mere mechanical strains is often much too little when the chance of oxidation of the surface is also considered.

I cannot help saying here, that the enormous recent multiplication of railway and bridge structures composed of slender wrought-iron bars, gives me some alarm for the future; for I cannot bring myself to believe that they will, or can, be efficiently preserved from oxidation for any great duration of time: and it must be recollected that these *bar* structures often depend on such a principle that the failure of one part of them (like that of a link of a chain) would destroy the stability of the whole.

I cannot, for instance, think that the saving of a few thousand pounds of expense was sufficient to justify the metropolitan authorities in adopting this sort of structure for such important national monuments as the public bridges at Westminster and Blackfriars. Their predecessors were wiser; for the handsome stone structures of London and Waterloo bridges will be the glory of the nation centuries after their flimsy and cheap iron rivals have rotted away.

CHAPTER VI.

MALLEABLE IRON—(*continued*).

Different Qualities in the Market.

202. I have repeatedly remarked how much wrought iron *varies* in almost every quality it possesses—in tenacity, in compressive strength, in pliability, in ductility, in hardness, in toughness, and so on.

But it may naturally be asked, Is the quality of the iron we use to be always a matter of uncertainty? or, if not, what guide can we get for the *choice* of iron, so as to ensure its fulfilling the conditions of quality we require from it?

This leads us to consider the varieties of choice afforded by the different kinds and qualities of iron which are found in the market. We see offered for sale many kinds of malleable iron, coming from many different districts, made by many different makers, costing widely different prices, and known by many different descriptive appellations, indicative of greater or less differences in quality. These distinctions, therefore, must form an essential subject of study to the engineer.

On this point, however, I must insist on the great value of the knowledge gained by *practical experience*. No amount of school study or book-learning will ever teach a man how to use iron to the best advantage: to do this he must have learnt the various properties and qualities of the different

kinds and makes of the material by actually using and observing them; and the want of this sort of knowledge, no amount of information otherwise imparted can ever efficiently supply.

All I can pretend to do here is to make you acquainted, as far as I can, with what we know generally of the different kinds and makes of iron, that can be identified and obtained in an ordinary commercial way.

Foreign Irons.

203. Probably the best irons practically obtainable are the foreign ones; chiefly from *Sweden*. These are made from good ore, smelted with charcoal, the product being very fine and comparatively pure iron, generally soft, and tough, and of good tenacity.

The Swedish irons are mostly used for making steel, for which, in consequence of their comparative purity, they are well adapted. The production of them is but small, they are very expensive, and consequently they are scarcely ever used for structural purposes.

Best Yorkshire Iron.

204. But, fortunately, we are able to produce also a very fine quality of iron in England, the manufacture of this class of material having been undertaken expressly in a certain iron-producing district in the immediate neighbourhood of Leeds and Bradford, in Yorkshire. The largest and, I think, the oldest firm making it is the *Low Moor Company;* and this class of iron has consequently been called either *Best Yorkshire* or *Low Moor* iron.

The latter name, though still often used, is not strictly appropriate, as there are now several other firms besides the

Low Moor Company, who make this best iron. I shall, therefore, always call it *Best Yorkshire iron.*

In addition to the Low Moor Company, there was another, the *Bowling* (close by), which made this iron at an early period. These two companies had a particular iron ore on their land, and also a particular quality of very fine coal; and it was asserted that both this ore, and this coal to work it, were essential to make this first-class iron.

By degrees, however, it was found that pig from other sources, if properly selected and worked, would answer the purpose; and as the demand for this iron has increased, other houses have successfully undertaken its manufacture; but all in the same immediate neighbourhood. I may mention six firms, *viz.*:—Low Moor, near Bradford; Bowling, near Bradford; Farnley Iron Works, near Leeds; Cooper's Iron Works, Leeds; Taylor's Clarence Works, Leeds; and Monk Bridge Works, Leeds.

There are some other firms, both in this and other districts, who occasionally manufacture *special* kinds of iron of high quality, but those I have named are acknowledged as of established character for supplying the ordinary market with *Best Yorkshire iron.*

205. The manner of making this iron has already been described in Art. 63. To ensure a good result the greatest care and attention must be given through the whole process, and if in any stage of it any signs of failure or deterioration should appear, the faulty pieces must be thrown aside. The large price which best iron sells for enables the manufacturers to do this; and, indeed, it is only the assurance that all this care is taken which warrants the price charged.

206. The peculiar merit of best Yorkshire iron is, that, in the first place, it combines in itself a high degree of every

good quality that iron should possess; and secondly, it has the great and special recommendation of being highly *uniform* and *trustworthy*, and it may therefore be used with much more confidence than iron of lower qualities.

We might find specimens of other iron more tenacious, harder, or more ductile; but we could scarcely ever get these qualities all combined in one specimen; or if we could, it would be only accidental—we could not rely on getting it uniformly the same.

207. The tenacity of best Yorkshire iron is generally high.

Above thirty bars of three different makers were tested by Mr. Kirkaldy, and the breaking weight, per square inch of original area, came out between 26 and 30 tons—the mean being 27½ tons.

208. Then the ductility and toughness are very high, and also very uniform.

The ultimate elongation of the iron just mentioned varied from 0·20 to 0·26 per unit of length—mean 0·24.

The work done in rupture was—

Highest	9500
Lowest	5700
Mean	7400

But the toughness is well established by experience of the manner in which this kind of iron works. It is quite devoid of the defect of *brittleness* or *cold shortness;* for it may be knocked about, and indeed often bent double, when cold, without even cracking.

209. Similarly, it is also free from the defect called *red shortness;* it is perfectly malleable when *hot*, and will stand almost any kind or extent of *working in the forge*, without deterioration.

It is *sounder*, more free from laminations and defects, owing to its being made chiefly in larger blooms (not piled), and more thoroughly and forcibly worked.

210. And it is very *hard*, or at least may be made so when required, so as to stand *wear* exceedingly well. Many inferior kinds of iron are also hard, but in these the hardness is almost always accompanied by *brittleness*, which is not the case with best Yorkshire iron. In this, therefore, we have tenacity, hardness, and toughness all combined.

211. The fracture of best Yorkshire iron may be either crystalline or fibrous. In the larger articles, principally hammered, such as tyres, axles, &c., it is usually crystalline, the crystal being of a fine grain. In rolled bars of smaller size, which are often made to be peculiarly tough, it shows a fine silky fibre.

212. Best Yorkshire iron fetches a high price. I shall give you hereafter some prices of various kinds of malleable iron, but we may say roughly, that best Yorkshire iron is not far from twice the price of the common material.

Now, no doubt, this price is high, not only in comparison with other kinds of iron, but also positively as regards the actual cost.

But it must be recollected that the selling sum includes not only the price of the article itself, but also a charge for the *guarantee* as to the uniformity and excellence of the quality; so far at least as care and attention can go.

The manufacture of iron is always uncertain; the only assurance we can have of its quality is by knowing that every possible care has been used in its preparation; and it is a condition of the established reputation of the houses who make this iron, that they undertake to give this care, in consideration of a high price paid them.

We know that *for* this price they can afford not only to select the best material and to take the greatest care in the making, but also to be liberal in their rejection of iron found imperfect during any stage of its progress. It is more to their interest to put aside faulty material than to risk their reputation by sending it out for sale; and hence we have the best assurance that we really get the best possible article. For, I repeat, it is the *uniformity* of the quality of best Yorkshire iron, and the confidence with which it may be used, which forms one of its best recommendations.

213. Best Yorkshire iron is, or at least ought to be, used for all purposes where a superior, trustworthy material is of sufficient importance to justify a little extra expense.

It is used in locomotives for cranked and straight axles, wheel tyres, and all iron working parts, as well as for the boiler plates. In all boilers it is, or ought to be, used for specially important parts, as fire-tubes, &c.; and in ship work such plates and other pieces as have to undergo sharp bending or other severe trial without injury are made of best Yorkshire iron.

Staffordshire Iron.

214. The qualities of iron below best Yorkshire are so various that it would be impossible to describe or even to enumerate them.

They are made in several iron districts, Wales and Scotland producing considerable quantities; but probably the principal part of the wrought iron used in England for manufacturing purposes comes from the great iron and coal fields of the Midland Counties, of which Staffordshire is the chief; and hence this iron, as a mass, is called *Staffordshire iron.* Indeed, it is not uncommon among iron users

to call all malleable iron "*Staffordshire*," which is not best Yorkshire.

215. There are some exceptional qualities of iron, both Staffordshire and Welsh, made in special modes, and for special purposes.

But omitting these, and treating of the ordinary commercial kinds, and taking *Bar iron* as an illustration, we may consider that there are three kinds of the material usually found in the market.

The first is called *Merchant Bar*, or *common iron.* This is the lowest or commonest kind of malleable iron usable for smiths' work. It is generally of inferior and untrustworthy quality, hard, brittle, and will not work well. It is used therefore for the commonest purposes, where but little smithing is required.

The second quality is called "*Best*" iron. This is of a better and more trustworthy quality, generally tougher and more ductile, and better adapted for smithing. It is the kind of iron most used for ordinary good work; and it is very customary in specifying wrought-iron work, to state that it shall be made from iron of a quality equal to "*Best*" Staffordshire.

The third is an *extra quality*, called "*Best Best.*" This is peculiarly made for chains, rivets, and other special purposes where extra toughness is desired.

216. It must be understood, however, that these classifications are *exceedingly general*, each class comprising an enormous variety of kinds and qualities—to choose between which is impossible without the aid of practical experience.

The guide which practical men have, is in the *brand* or *trade mark*, which all firms who profess to make a respectable article, stamp on their iron. These marks are known to

all people who use iron on a large scale; and the same brand is understood to indicate a certain degree of uniformity in the quality. All iron of decent quality ought to be stamped with a known mark, and though it may not follow that all marked iron is good iron, yet it may be safely assumed that *unmarked* iron is generally *bad*, and ought not to be used where quality is of any importance. The makers of best Yorkshire iron all impress the name of their firms on every article they manufacture, and now often add the date when made.

The makers of other classes of iron generally use abbreviations or marks understood in the trade.

The iron marked S C (called S. C. Crown iron) is a *Best Best* iron, made by Messrs. Bradley, of Stourbridge, and is in great repute in the London market for making bolts, nuts, &c.

It would be impossible to give a list of all the trade marks; the following are a few of the best-known Staffordshire houses:—

B. B. H. is the mark of Messrs. Barrows and Hall.

A Mitre, that of Messrs. Williams.

A Lion, that of the British Iron Company.

L. W R D, that of iron made at Lord Dudley and Ward's works.

These, and indeed almost all large firms, make the three qualities of Staffordshire iron. When it bears no mark, except the name, it is the commonest or *Merchant Bar* kind; the two better kinds are marked in addition "*Best*" and "*Best Best*" respectively.

These irons, of course, vary in almost every possible way, in tenacity, toughness, ductility, hardness, facility of working, and so on. It is only by long practical experience that

their qualities can become known; and even then they are always more or less uncertain.

For general purposes, however, of bar iron, a quality that breaks tough and fibrous, and that is found to work tolerably well in the forge, is considered a useful and eligible iron.

Different Forms of Malleable Iron in the Market.

217. I now pass on to speak of the various *forms* in which wrought iron is obtained in the market, for the purpose of making mechanical structures.

You will know the difference between *cast* and *wrought* iron in this respect.

In the former, cast iron, we give an order to the maker of the material, *i. e.* the founder, to supply us at once with any shape we require.

In wrought iron we may occasionally, to some extent, do the same thing, by ordering *forgings*, which are masses of wrought iron *forged* into given shapes.

But this is exceptional. By far the more common way is to purchase the material in certain fixed shapes (adopted for convenience in the market), and then to build or fashion these into the structure desired.

These marketable shapes therefore, and the qualities and peculiarities incidental to them, require some notice.

218. The most common and useful form is *Bar iron.* This consists of bars usually about 15 feet long, and of various transverse sections.

In the first place there are *square bars; i. e.* bars whose transverse section is a square  ; and these are to be had of various dimensions, from about $\frac{5}{8}$ inch on the side, up to 3 or $3\frac{1}{2}$ inches.

And then there are *round bars*, whose section is a circle, of about the same range in diameter.

Square or round bars of $\frac{1}{2}$ inch and less are called *rods*; or if much smaller, they become *wire*. On the other hand, it is not customary to keep bars much larger than 3 or $3\frac{1}{2}$ inches square or round. If wanted, they are forged specially.

Then there are what are called *flat bars*. This is a name given to bars of rectangular section, in which one side is greater than the other.

These are of a great variety of sizes; the most generally useful being kept in stock, and special sizes being rolled to order. The dimensions of flat bars may vary from 1 inch to 6 or 7 or more inches broad; and from $\frac{1}{2}$ inch to $1\frac{1}{2}$ or 2 inches thick; and of these dimensions they will be rolled the same length as other bars, say about 15 feet.

But if they are required to be more than about 9 inches wide, they are made shorter, and then become *plates*.

Bar iron is made of all possible qualities, from *Best Yorkshire* down to the veriest rubbish that will hold together.

Bars are of course made by rolling: in the best kinds the iron is hammered in the preliminary stages of its manufacture, the rolling being the last process, to give uniformity of section.

The term *Bar iron* is understood only to apply to bars of the simple forms I have alluded to, *viz.* square, round, and flat. There are many other shapes in which bars of iron are rolled, but these usually take different names, and I shall speak of them hereafter.

219. The next form of wrought iron to be mentioned is that of *Plates*.

Wrought-iron plates are made of any *thickness*, from about $\frac{1}{8}$ or $\frac{1}{4}$ inch to 1 inch, in gradations usually measured by

16ths of an inch. Thus after $\frac{1}{4}$ (or $\frac{4}{16}$) comes $\frac{5}{16}$; then $\frac{3}{8}$ (or $\frac{6}{16}$); then $\frac{7}{16}$, and so on. If very thin, they are called *Sheets.*

The lengths and breadths of plates are very various. They are usually made to order, of such dimensions as the purchaser desires. When they exceed about 3 or 4 cwt. in weight, they bear an extra price.

Plates are made by *rolling.* The iron is prepared, in the preliminary process, in *slabs* of a flat shape; these are piled one on the other, subjected to a welding heat, and then rolled out to the required thickness; after which the rough edges are cut off with large shears, worked by machinery, so as to give a fair shape (usually rectangular), of the length and breadth required.

Now the rolling produces (if the iron be tolerably good in quality) a fibrous structure to a certain extent, the length of the fibre being parallel to the direction of the rolling. During the manufacture of the plates they are rolled in both directions; but when one dimension much exceeds the other, as is generally the case, the plate gets more rolling in the direction of the length, and hence the fibrous texture is more perfectly defined in this direction.

220. For this reason the qualities of a rolled plate are generally somewhat different in the two directions, longitudinal and transverse respectively; and I shall have occasion to distinguish between them by these names.

I shall call, for example, the *longitudinal* tenacity the strength when pulled parallel to, or broken across the fibre. The *transverse* tenacity is that developed by pulling at right angles to the fibre, the fracture being parallel to it.

The qualities of wrought-iron plates are so important that they have been frequently investigated, separately and distinctly from other forms of wrought iron.

221. And first, as to the tenacity. It might be reasoned that, since it has been found that when wrought iron is rolled, or drawn into small bars, it gains in tenacity, therefore, by analogy, the rolling into thin plates might also improve it; so that, on this principle, plates might be expected to be stronger than bars.

But this is not so; they are really weaker by about 20 per cent.

The usual rough popular estimate is 25 tons for good bars, and 20 tons for good plates; but I must give you the data obtained more carefully.

Mr. Fairbairn, in 1838, tried experiments on twenty pieces of plate of various kinds, and obtained a tenacity varying from about 19½ to 25½ tons per square inch; and he found reason to think there was no great difference in the tenacity, whether the plate was drawn in the direction of the fibre or across it.

But this latter conclusion has not been confirmed by later experiments; indeed, Mr. Fairbairn himself, in subsequent trials, arrived at a different conclusion. It has now been, I think, conclusively shown that, for plate of *good quality*, the longitudinal tenacity is greater than the transverse.

Some experiments on the strength of plates were tried by Mr. Stephenson's direction at the construction of the Britannia Bridge. In the first instance he tried several plates all pulled in the direction of the fibre. They were ½ inch, ⅝ inch, and $\frac{11}{16}$ thick; and the resulting longitudinal tenacity varied from 18 to 22 tons per square inch, giving a mean of 19·6 tons. The iron was supplied by different makers, in Staffordshire, Derbyshire, and Shropshire.

Mr. Stephenson then tried the comparative strengths when broken, either *parallel with*, or *across* the fibre.

Two plates were selected, and from each plate two specimens were taken, of suitable form for testing. One specimen

in each pair was cut out in the direction of the fibre, and the other across the fibre; thus in all other respects they were precisely similar.

The results were, for the ultimate strength—

Drawn the direction of the fibre—

1st plate	19·66 tons per square inch
2nd „	20·2 „
Mean	19·93 tons (longitudinal tenacity).

Drawn across the fibre—

1st plate	16·93 tons per square inch
2nd „	16·7 „
Mean	16·8 (transverse tenacity).

Or about 18 per cent. weaker in the latter direction.

Mr. Kirkaldy tried a great number of plates of various qualities and makes, in both directions.

Taking for the present the longitudinal tenacity (the strongest way of the plate), the *Best Yorkshire plates* gave (per square inch of original area)—

	Tons.
Minimum	21
Maximum	28
Mean	24½

Other makes of plate varied from—

	Tons.
Minimum	16½
Maximum	27½
Mean	22

Comparing the longitudinal and transverse strengths of the plates, he found the latter generally about 10 per cent. less than the former; rather less difference than Mr. Stephenson had made.

Mr. Fairbairn's later experiments give—

	Longitudinal tenacity.		Transverse tenacity.
Best Yorkshire plates	28·6	..	23·4
Mean of ordinary plates	23·1	..	21·3

We may therefore take as a general average for the greatest or *longitudinal* tenacity—

	Tons.
Best Yorkshire	25
General	20

And for the transverse tenacity about 10 per cent. less.

The Admiralty test is—

	Longitudinal tenacity.		Transverse tenacity.
For Best Best plates	22	..	18
For Best plates	20	..	17

The test prescribed by Lloyd's ship-building rules is 20 tons.

M. Morin (Art. 59) gives the particulars of a series of experiments on French plates, the means of which give for—

	Kil. per square mill.		Tons per square inch.
Longitudinal strength	34·43	..	21·8
Transverse strength	31·76	..	20·2

222. The *ductility* of plates is as important as their tenacity; for all I have said in regard to the importance of this qualification in iron generally applies with almost increased force to plates for ship-building.

Mr. Stephenson tried the ductility of the plates I have mentioned in his Britannia Bridge experiments, and he found it very variable, even more variable than the strength; the ultimate extension *longitudinally* varied generally from about 0·017 per unit of length to 0·125. In one specimen it was only 0·0062.

And as a warning how little use the *tenacity alone* is, as an

index of the effective quality of the plate, it was found that the brittle crystalline irons, which broke suddenly with the minimum elongation, actually supported more weight than those much more fibrous and ductile.

Mr. Stephenson also tried the *transverse* ductility as compared with the *longitudinal*, and found the former only *half the latter*, an additional advantage of much weight in favour of the strain being put in the longitudinal direction.

Mr. Kirkaldy also tried the ductility of plates with much care.

The results were, for—

Best Yorkshire (longitudinal ductility) ..	Max.	0·170
" " " ..	Min.	0·110
Mean		0·134
Other kinds (longitudinal ductility)	Max.	0·130
" " " ..	Min.	0·033
Mean		0·080

He also found the transverse ductility less than the longitudinal in the average proportion of 5 to 9, about the same as that given by Mr. Stephenson.

It is to be remarked, that the difference between the longitudinal and the transverse strengths will be *less* in the *inferior* than in the superior qualities of iron, by reason of the *fibre being less developed* in the worse and more brittle kinds; indeed, the latter will probably be as good (or rather as *bad*) in one direction as in the other.

223. When we combine the tenacity and ductility together, by estimating the value of Mallet's coefficient of work done in rupture, we obtain a striking contrast not only of the values of different kinds of plate, but also of the difference in

value of the same plate, in its longitudinal and its transverse directions.

	Longitudinal.	Transverse.
Best Yorkshire.		
Maximum	5450	2725
Minimum	2600	1300
Mean	3750	1875
Ordinary.		
Maximum	3820	1910
Minimum	315	315
Mean	1800	1000

224. The data I have given will show that the qualities of plate purchasable in the market vary as much as those of *bar*, if not more.

The *Best Yorkshire plates* are all that can be desired in every respect; they are not only tenacious, ductile, and tough, but they are admirably adapted for forging, bending, punching, and all workshop manipulations, without suffering injury; and like all other iron of this class, they can be thoroughly depended on. They are, however, expensive, as I have previously explained.

Below Best Yorkshire come Staffordshire and other plates; and these are generally classed, like bar iron, in three classes.

The first are common plates, bearing no mark but that of the maker, and sometimes not even that. It is, however, one of Lloyd's rules, that all iron, plate, beam, and angle, is to be legibly stamped in two places with the manufacturing trade mark.

These common plates, when intended for boat-building, are usually called *boat plates*, and their quality may be anything that will hold together. There are sometimes decent

qualities to be found of this class; but it is often very bad, and the best ship-builders ignore it altogether.

The next quality is called *Best*, and is marked with this word. These plates are worth about 1*l.* a ton more than the common, and are, or ought to be, good, tenacious, and ductile; they should stand bending cold to a certain extent without breaking. They may be used with confidence for boat-building, but it is not always that the expense of them will be submitted to.

The third quality is called *Best Best;* it is worth about another 1*l.* per ton extra, and is tougher and more ductile than the last, but still not equal to Best Yorkshire. No quality under this ought to be used for steam-engine boilers.

The Admiralty use "Best Best" for the hulls of their vessels. The 'Bellerophon,' for example, built at Chatham, has all the more important portions *Best Best plate*, single Best being used in certain parts when the quality is of less moment.

I need hardly say that the *quality of plate* to be used for building the hulls of iron ships is a subject of the most vital importance.

It has been pertinently remarked, that in the eyes of the merchant or ship owner, generally, iron is iron; he probably does not know the almost infinite varieties of quality that are comprehended under this general name, and may little think that the hull of a ship he may have got built cheaply, may be not much more trustworthy than if it were made of glass!

And I would repeat again what I have so often said before, that it is not *tenacity alone* which must be taken as the criterion, inasmuch as I have shown you that the very *worst* qualities of iron may sometimes show a high tenacity.

By far the more important qualities for ship purposes are ductility and toughness; for on the state of the iron in regard

to these may depend whether the ship may safely withstand shocks and buffetings in cases of peril, or whether she may crumble to pieces, and instantly go to the bottom.

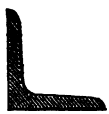
225. When plate iron is less than about $\frac{1}{4}$ of an inch in thickness it becomes *sheet iron;* and when this is cut up into narrow strips like ribbons, they take the name of *hoop iron.*

M. Morin (Art. 61) gives experiments which show the ultimate strength of hoop iron to vary from 28 to $38\frac{1}{2}$ kil. per millimètre, or from 18 to $24\frac{1}{2}$ tons per square inch. Hence the principle of increase found with wire does not apply to hoop iron.

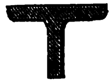
When clean sheet iron is immersed in a bath of melted tin it becomes covered with the latter metal, which combines chemically with its surface, and adheres firmly. This is the well-known *tin plate.* The iron used for this is of a specially good quality, which is very soft and ductile, and will stand without damage the varied treatment it has to undergo in the manufacture of utensils and other articles made of this useful material.

226. I now pass on to other forms of wrought iron.

In speaking of bar iron, I told you this term was usually confined to bars of *simple sections,* such as square, round, and flat. But there are other shapes of bars rolled, which take peculiar names, and which are very useful in forming structures of wrought iron.

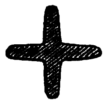
The chief of these is *angle iron.* This is rolled in long lengths, like common bar; but its section is of the shape of the letter L, thus  It is one of the most useful shapes in the formation of structures of wrought iron. Angle iron is made of various sizes, from $1\frac{1}{2}$ inch to 6 inches, or

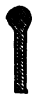
thereabouts, on either leg, and the legs are frequently of different widths. The thickness varies from about $\frac{1}{4}$ inch to as much as 1 inch in large sizes.

Another form of section, also very useful in structural combinations, is what is called T iron, thus  And there are forms called

Channel iron .. .. 

Half-round iron .. .. 

Feathered iron .. .. 

Bulb iron .. .. 

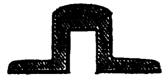
Beam or H iron .. .. 

And many other fancy forms; indeed, by the operation of rolling, if proper grooves are cut in the rolls, almost any desired shape may be procured.

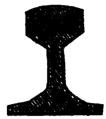
Rails, for example, are rolled in great varieties of shapes, as for example,

Double-headed rail .. .. 

Bridge rail .. ..



Vignoles or flat-bottomed rail .. ..



Sections which weigh from 30 or 40 to 80 or 90 lbs. per yard.

The quality of angle iron, T iron, and the small fancy irons I have mentioned is, of course, various, according to the make; but it is generally superior to common bar iron, for the reason that a better kind of material is necessary in order to enable the iron to take the desired forms in the rolls; for if the very worst kinds of metal were used (such as are often sold in plain bar), it would not be sufficiently ductile and workable to bend into the grooves of the rolls, but would crack and break to pieces.

Mr. Kirkaldy tested several varieties of angle iron, beam iron, and strap iron, of the kinds ordinarily used in shipbuilding, and obtained the following results:—

The Best Yorkshire iron stood, of course, the first in this, as in all other respects. Angle iron of this make gave tenacity 26 to 28 tons. Ultimate elongation, 0·21.

Other kinds of angle iron gave tenacity varying from 19 to 26½ tons. Elongation, 0·154 down to 0·058.

Cost of Wrought-iron Work.

227. In speaking of cast iron I have mentioned something about the *cost* of articles made in it, calling your attention to the fact that one great advantage of this material is its

cheapness—due to the facility which the process of moulding and casting gives to the formation of any required shapes in the material.

Now, *wrought-iron work* is *very expensive* in comparison with cast; for not only is the value of the *material itself* greater, but also the *cost of working* it into required forms enhances the price to several times the value the same thing would have in cast iron.

But, still, the peculiar properties of the material render it, in a vast variety of cases, so much more valuable and appropriate than cast iron as fully to justify the extra cost.

And if we are willing to incur this extra expense, wrought iron presents good features in its malleability and ductility; the power of welding, punching, cutting, hammering, and all the varieties of contrivances included in smiths' work (which are totally wanting in cast iron), and by means of which we may succeed in fashioning wrought iron into almost any form we desire. And when to this we add the facility that we have of *building up* wrought-iron structures out of small and separate pieces by riveting, bolting, &c., we see that the material, though comparatively dear, is still well adapted to structural use.

It must not be lost sight of, that the comparative dearness of wrought iron over cast may be lessened, in very many cases, by the *diminution of weight* required in the tougher material. In cast iron, a considerable excess of strength is necessary to provide for accidental and unknown defects, as well as for the chance of fracture by concussions, &c., &c. But in the more trustworthy material, something important in weight may always be saved, and the cost diminished accordingly.

I will now give you some general notion of the *prices* of malleable iron, and wrought-iron work, in various forms. You must, however, clearly understand that I only profess

to do this very *approximately*, as prices vary considerably, not only in different districts, but at different times.

And much depends also on the places where the iron is to be delivered.

Best Yorkshire Iron per Ton.

Bar Iron—Under 2½ or 3 cwt., about 17*l.* and 18*l.*; increasing, as the weight increases, till 7 or 8 cwt. costs 25*l.*

Plates—Under 2½ cwt., 21*l.* and 22*l.*; increasing till 5 cwt. and upwards, 36*l.* and 37*l.*

Locomotive Tyres and Axles—According to weight, 20*l.* to 37*l.*

Locomotive Cranked Axles (rough from forge), 50*l.*

N.B.—These prices do not vary with small fluctuations in the market, and are nearly the same for all the firms that make this iron.

Other Iron (all delivered at works) per Ton.

Welsh Bar, 7*l.* to 7*l.* 10*s.*

Staffordshire Merchant Bar, 8*l.* 10*s.*; "*Best*" *Bar*, 9*l.* 10*s.*; "*Best Best*," 10*l.* 10*s.*

Common Boat Plate, Welsh or Scotch, 8*l.* 10*s.* or 9*l.*

Staffordshire Boat Plate, 10*l.*; "*Best*" *Plate*, 11*l.*; "*Best Best*" *Plate*, 12*l.*

Angle and T iron, say 1*l.* above bar of same quality.

Anchors, under 3 cwt., 28*l.*; 5 to 25 cwt., 24*l.*; 52 cwt., 30*l.*

Chain Cables, according to size, 15*l.* to 20*l.*; the smallest being the dearest.

Armour Plates, 30*l.* to 35*l.*

Plain Boilers, Best Best Plates, say 22*l.* to 24*l.*

Ships' Hulls, say 20*l.* to 25*l.*

Girder Bridges, 17*l.* to 25*l.*

Forgings, according to size and shape, from 25*l.* to 50*l.*

228. The following Table collects together the data hereinbefore given as to the principal properties of wrought iron:—

MECHANICAL PROPERTIES OF WROUGHT IRON.

	Maximum.	Minimum.	Mean.
TENACITY.	Tons per square inch.		
Bar—General	30	15	25
Best Yorkshire	30	26	27·5
Plate—General	27·3	15·(?)	20
Best Yorkshire	28·6	21	25
COMPRESSIVE STRENGTH	..	..	16
	Tons per 1 inch square.		
STIFFNESS (Modulus of Elasticity)	14,000	8000	10,000
DUCTILITY.	Ultimate elongation per unit of length.		
Bar—General	0·30	0·06	0·20
Best Yorkshire	0·26	0·20	0·24
Plate—General	0·125	0·017	0·08
Best Yorkshire	0·17	0·11	0·134
TOUGHNESS.	Work done in rupture of 1 inch bar 1 foot long.		
Bar—General	9500	730	5600
Best Yorkshire	9500	5700	7400
Plate—General	3820	315	1800
Best Yorkshire	5450	2600	3750
SPECIFIC GRAVITY	7·8	7·45	7·68

229. Let us now endeavour to sum up some of the most important points of knowledge we possess about wrought iron, in the same manner as we did for the *cast* form of the material.

a. All the mechanical properties of wrought iron are exceedingly variable, extending over a very wide range, according to the different makes and qualities existing in the market.

b. The tenacity, or tensile strength, of wrought iron is three or four times greater than that of cast, which determines the preference of wrought iron in all cases where it has to resist tensile strain.

c. But wrought iron is much *weaker* than cast iron in compressive strength, or strength to resist crushing, which should determine the preference of cast iron in cases of compressive strain.

d. Wrought iron of good quality has a great advantage over cast iron in its *ductility* and *toughness*, which peculiarly fit it for bearing shocks, concussions, and sudden strains.

e. In judging of the fitness of wrought iron for the purposes where shocks and sudden strains are likely to occur, the tenacity alone is not a sufficient guide; but the ductility and toughness must also be ascertained.

f. To judge of iron by its fracture requires much knowledge and experience, without which the appearances may often be misunderstood.

g. Large masses of iron are likely to be weak and uncertain in their internal portions, and on the other hand, iron gains much in strength by being drawn down to small sizes.

h. The hardness of wrought iron is very variable in different makes. Iron may be artificially hardened by cold hammering or cold rolling, but this hardness may be removed by annealing.

i. Wrought iron will bear the frequent repetition of a *moderate* strain without having its ultimate strength diminished thereby.

k. Wrought iron is very liable to damage by oxidation; it must always be well protected, and the protection must be carefully renewed at frequent intervals, for which purpose the surfaces must be made easily accessible.

l. The best kind of iron is that called Best Yorkshire iron, which has not only high tenacity, but great ductility

and toughness; and has, in addition, the great recommendation of being uniform and trustworthy.

m. Plates are generally inferior to bars in both strength and toughness, and their lower qualities are often uncertain and untrustworthy.

n. In the better qualities of plates, both the tenacity and toughness are considerably greater in the longitudinal than in the transverse direction; and therefore, as far as possible, the strain should be put in the longitudinal direction.

o. Wrought iron is dearer than cast iron, and it is much more costly to form structures in it. But on account of its greater strength, their weight may be generally much less than in cast iron.

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